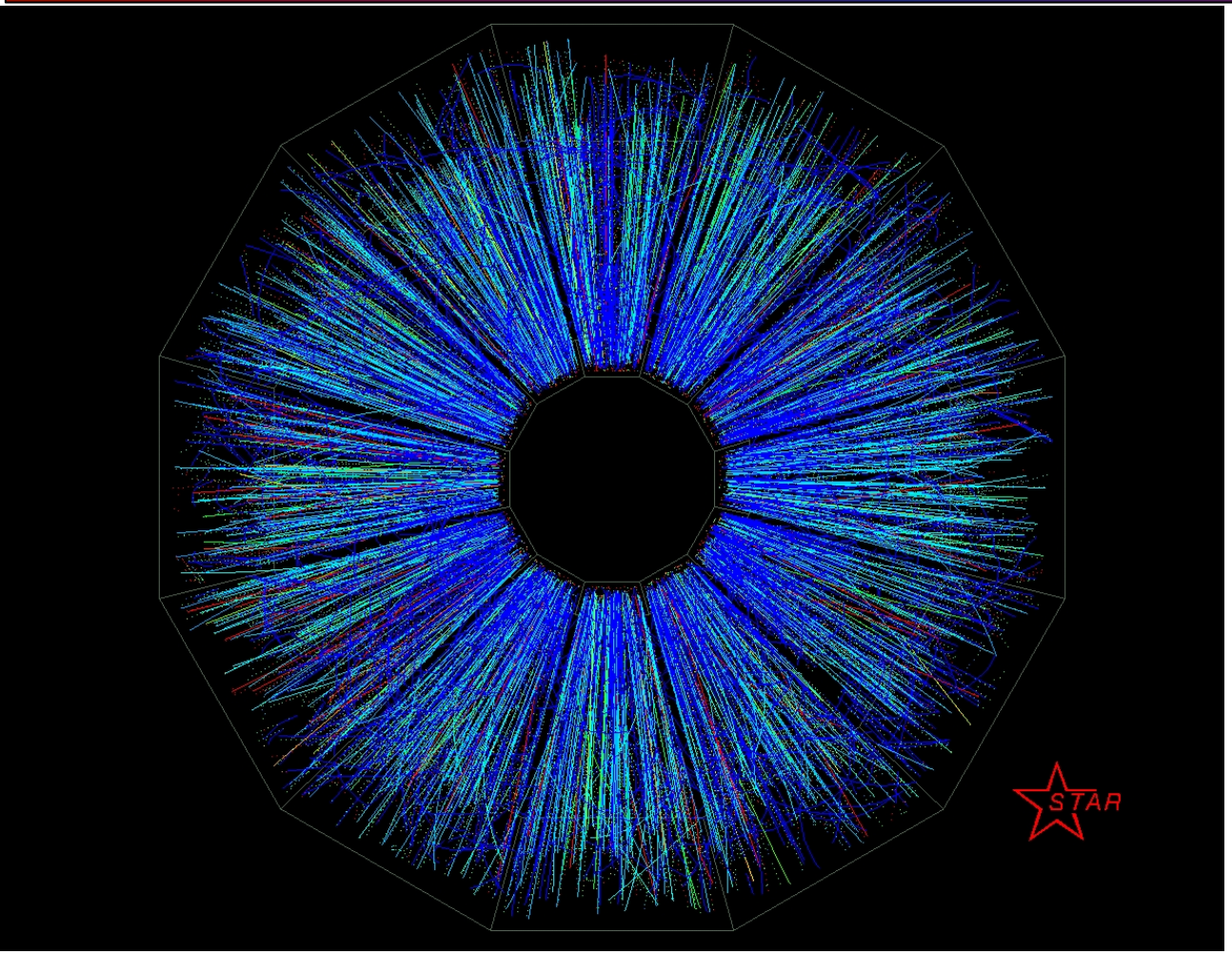
The next half-decade of physics with STAR



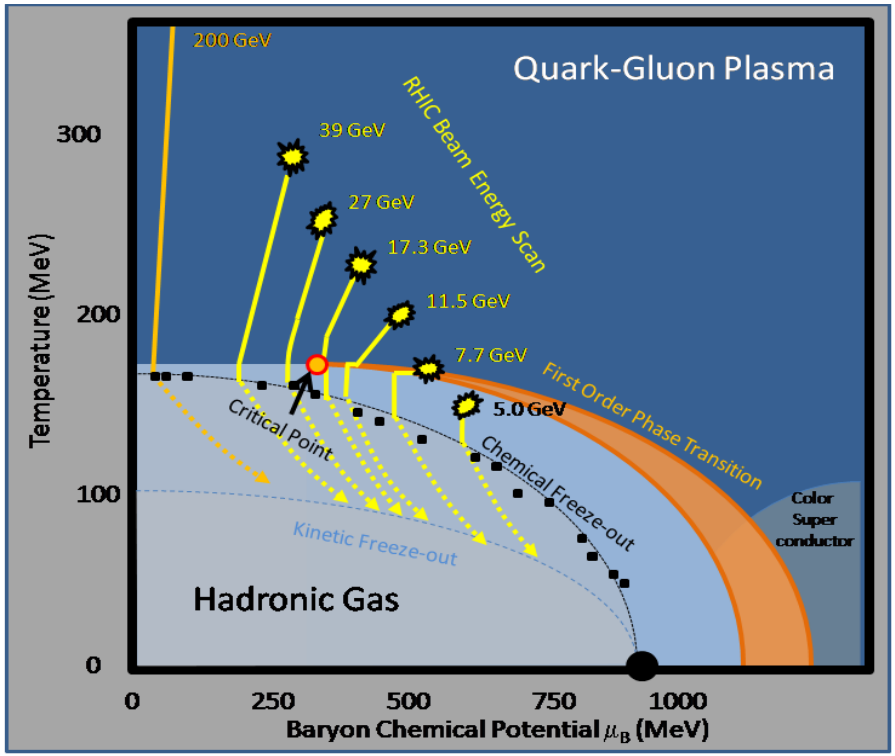
1st Collision
June 12, 2000

James Dunlop for the STAR Collaboration

BROOKHAVEN NATIONAL LABORATORY

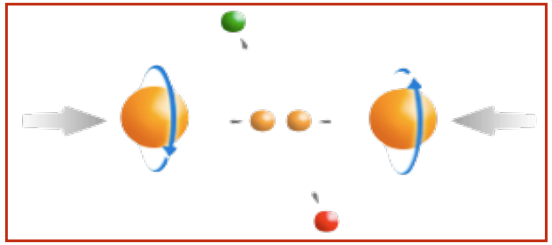
RHIC: Key Unanswered Questions

Hot QCD Matter

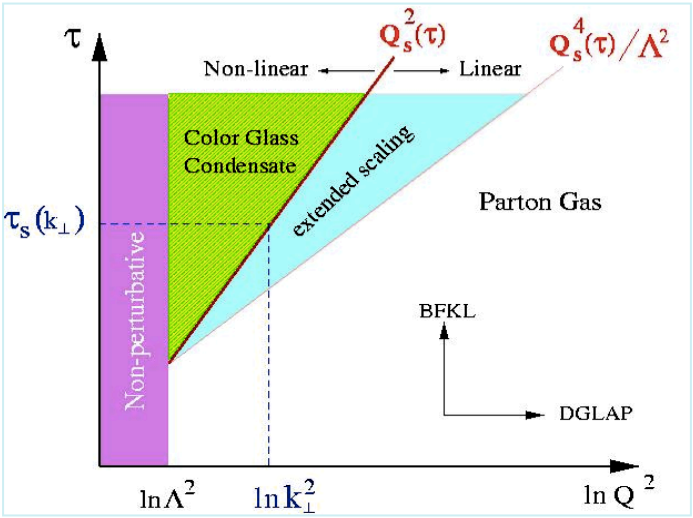


Properties of the sQGP in detail
Mechanism of Energy Loss:
weak or strong coupling?
Is there a critical point, and if so, where?
Novel symmetry properties
Exotic particles

Partonic structure



Spin structure of the nucleon
How to go beyond leading twist and colinear factorization?



What are the properties of cold nuclear matter?

STAR: A Correlation Machine

Tracking: TPC

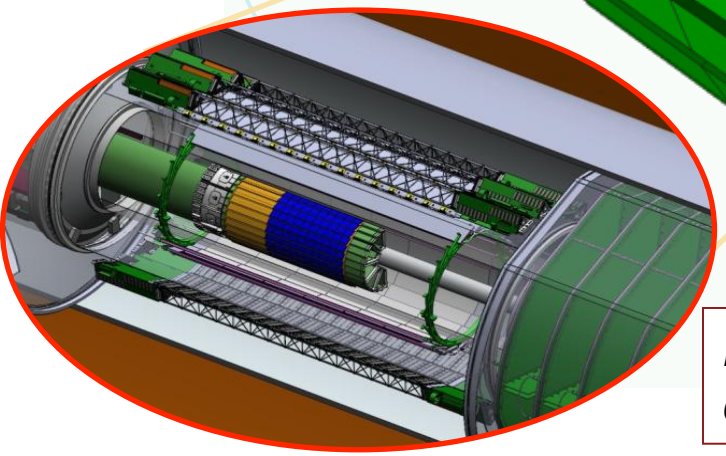
Particle ID: TOF

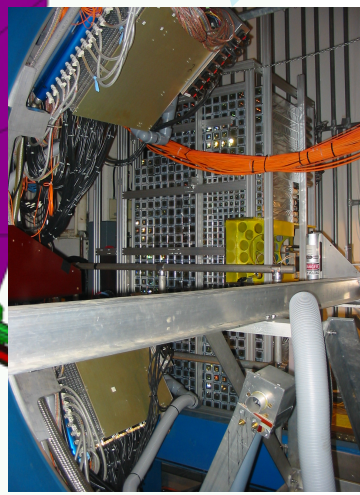
Electromagnetic Calorimetry: BEMC+EEMC+FMS
$(-1 \leq \eta \leq 4)$

Muon Telescope Detector (2014)

Upgrades:
Trigger and DAQ
Roman Pots Phase 2
Forward Upgrade

Heavy Flavor Tracker (2014)





Full azimuthal particle identification over a broad range in pseudorapidity

Forward Gem Tracker (2011)

How to answer these questions

Next 5 years

Hot QCD matter: high luminosity RHIC II (fb^{-1} equivalent)

- Heavy Flavor Tracker: precision charm and beauty
- Muon Telescope Detector: e+μ and μ+μ at mid-rapidity
- Trigger and DAQ upgrades to make full use of luminosity
- Tools: jets combined with precision particle identification
- Full use of the flexibility of RHIC with U+U, other systems

Phase structure of QCD matter: energy scan

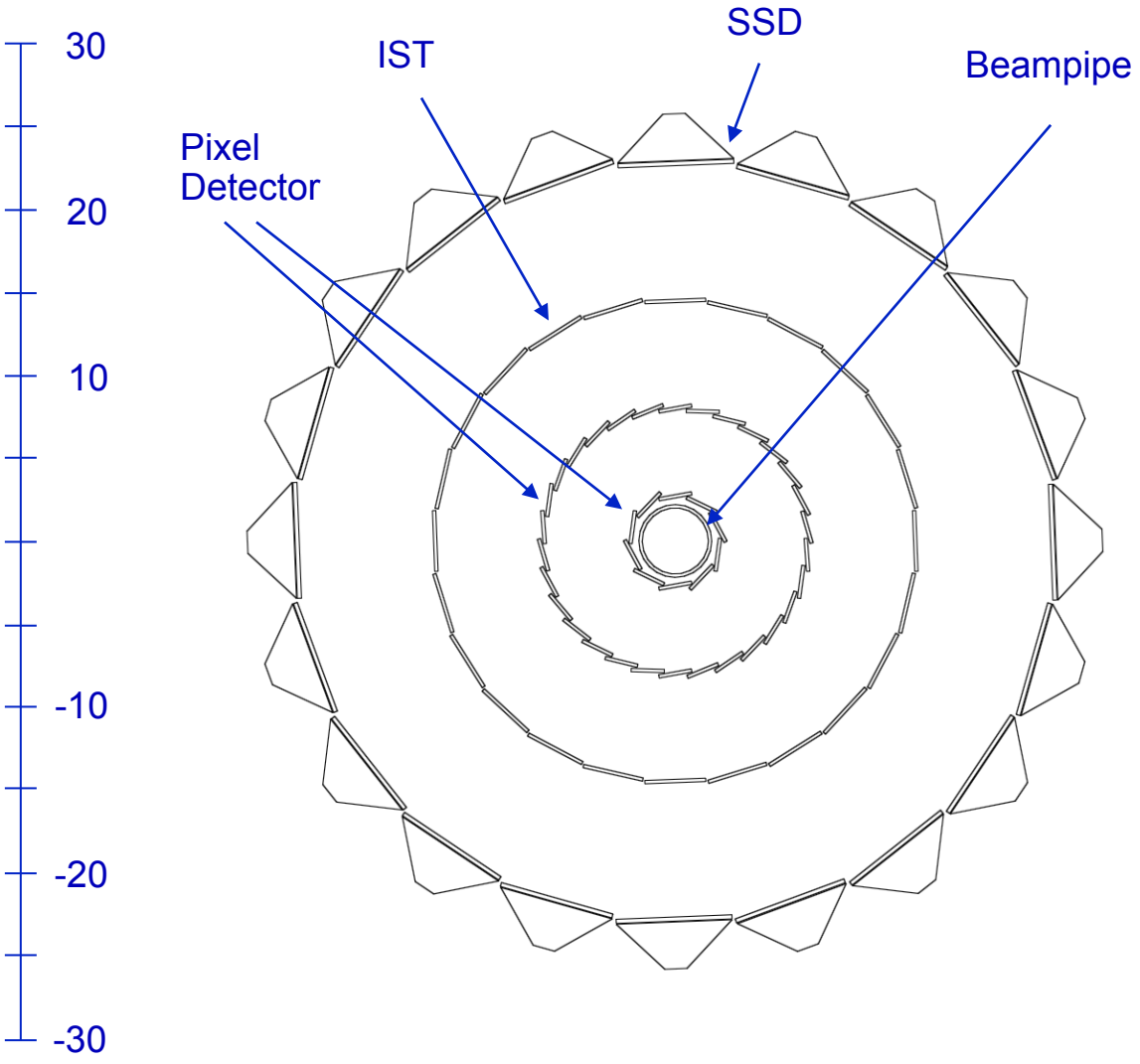
- Analysis of Phase 1, completed in Runs 10 and 11, followed by targeted fine-scale scan of certain energies

Partonic spin structure of the proton

- Gluon polarization: A_{LL} at 200 and 500 GeV with dijets
- Sea quark polarization: W A_L at forward and mid-rapidity
- Transverse spin phenomena

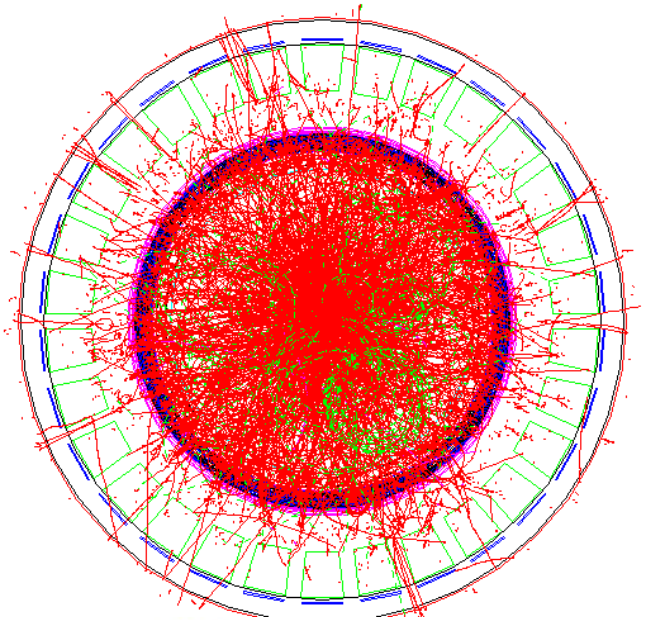
Hot QCD Matter

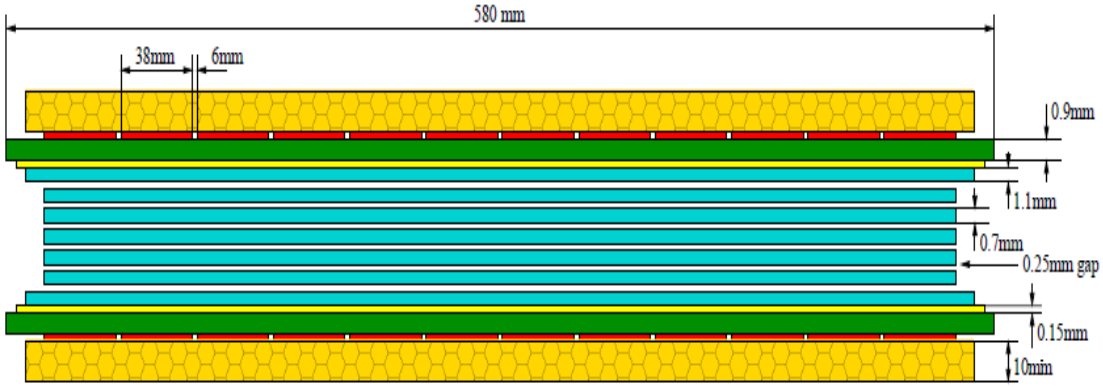
Heavy Flavor Tracker (HFT)

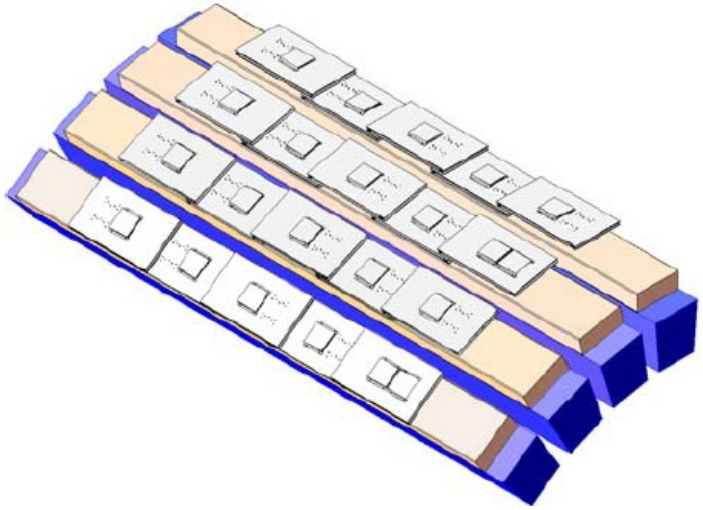


- **The HFT puts 4 layers of Silicon around the vertex**
- **Provides ~20 μm space point resolution on tracks**
- **Uniquely thin pixels**
  - **< 0.6% X_0/layer, targeting 0.32% X_0**
  - **Topological reconstruction of open charm at low p_T**
- **DAQ1000-level rate capabilities**
  - **(~ 800 Hz – 1KHz)**
- **Will be ready for the 2014 run**

Muon Telescope Detector (MTD)







Muon Tagger: use the magnet steel as absorber, TPC for tracking

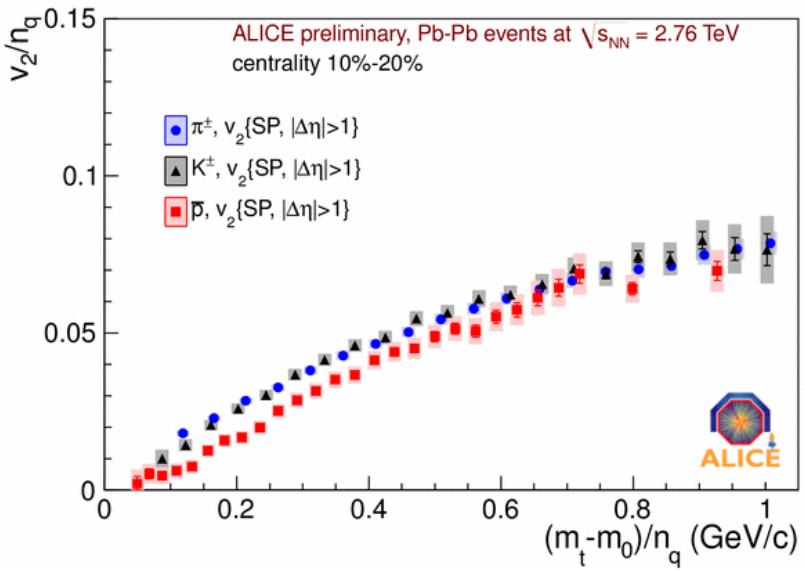
Acceptance: 45% for $|\eta|<0.5$

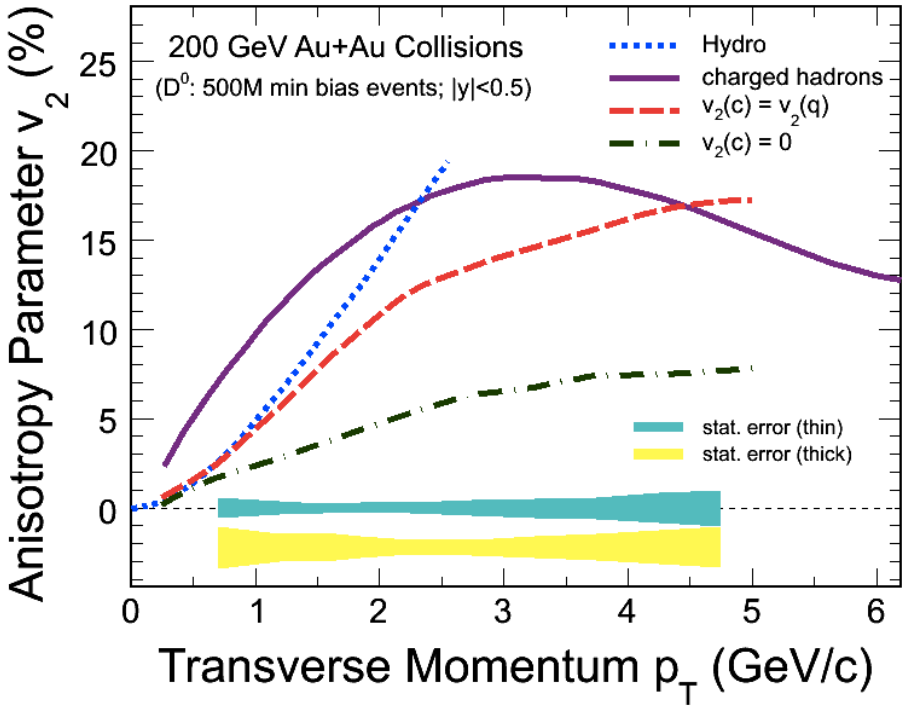
118 modules, 1416 readout strips, 2832 readout channels

Long-MRPC detector technology, HPTDC electronics (same as STAR-TOF)

Unique capability to identify muons at mid-rapidity at RHIC

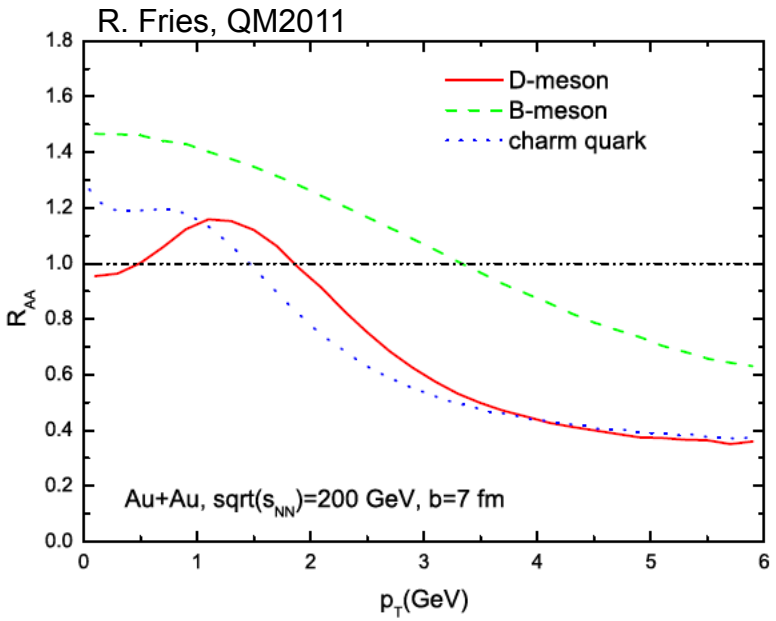
Properties of sQGP: charm flow

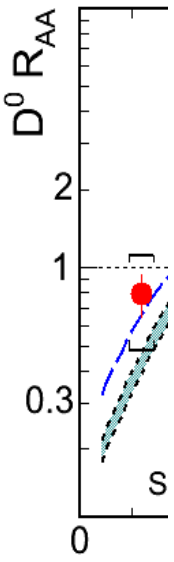


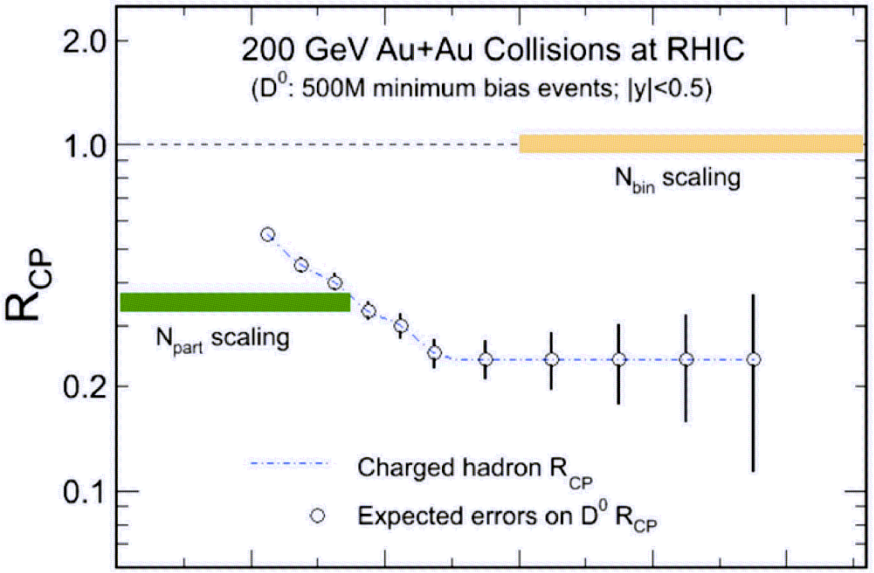


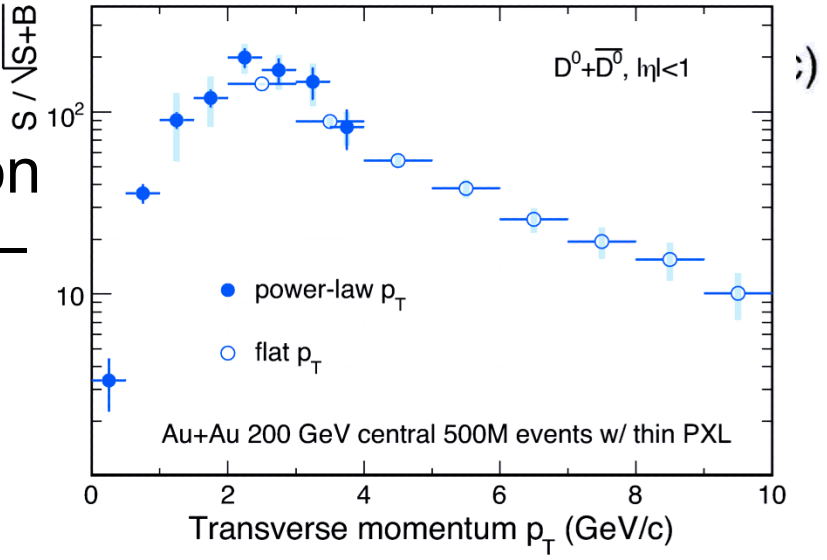
- Does charm flow **hydrodynamically**?
  - Low p_T is the hydro domain
- Heavy Flavor Tracker: unique access to **low-p_T fully reconstructed charm**

Charm diffusion: low p_T matters



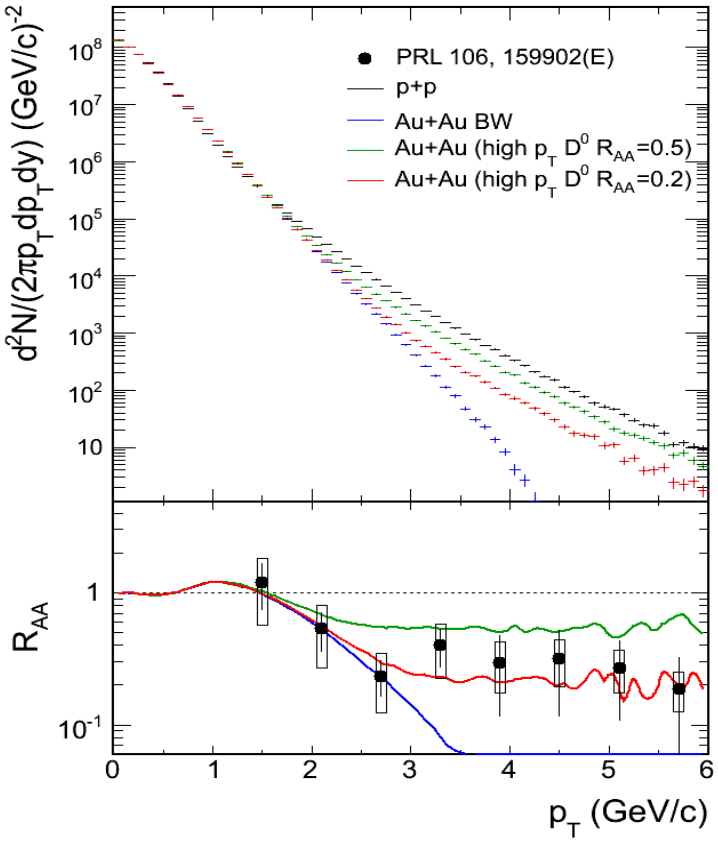


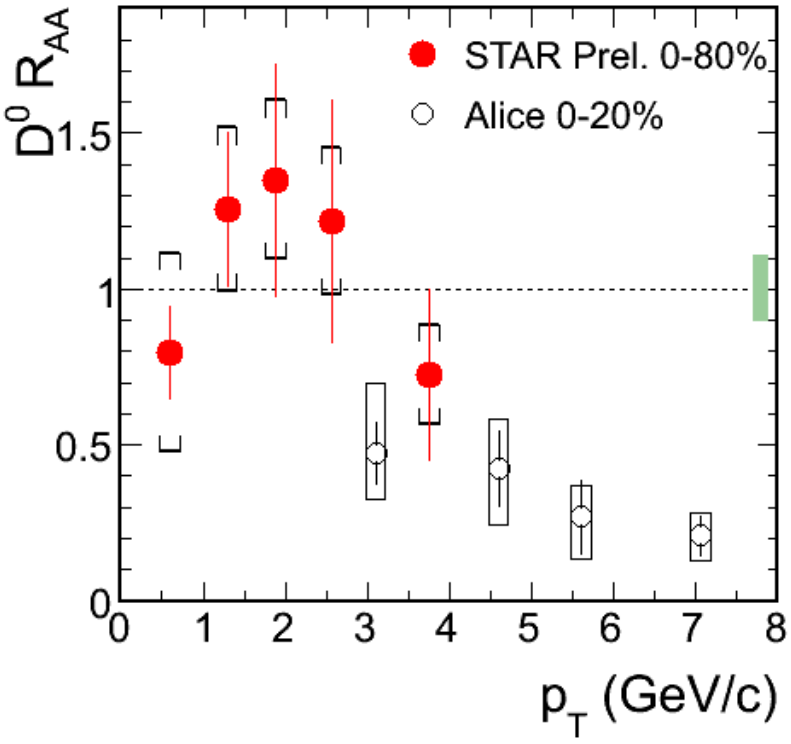




- Critical region for testing diffusion and hydrodynamic flow: p_T ~ 1 – 3 GeV/c
- ***STAR*** is just starting the exploration of this region
- ***STAR*** HFT is **optimized** for this

Low p_T is unique to the STAR HFT



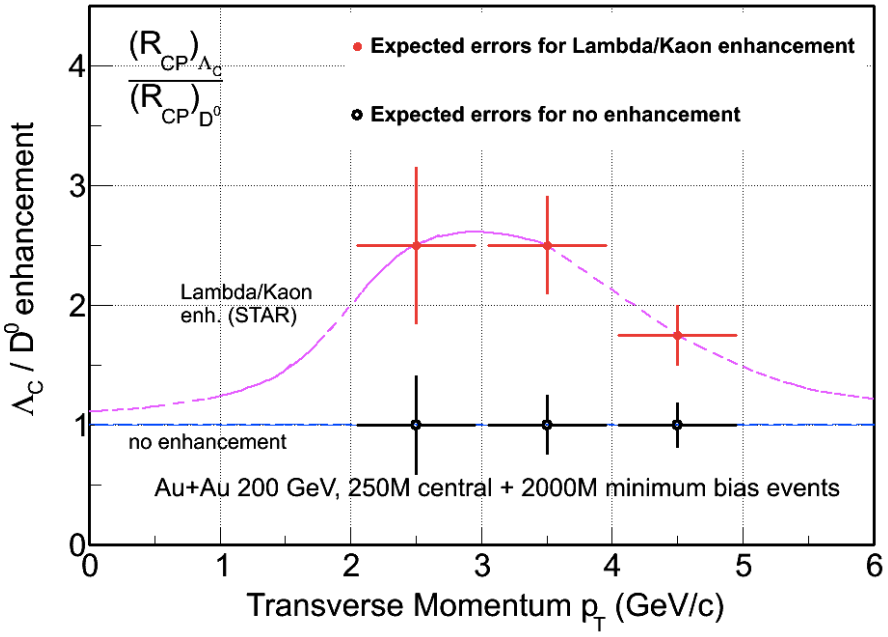


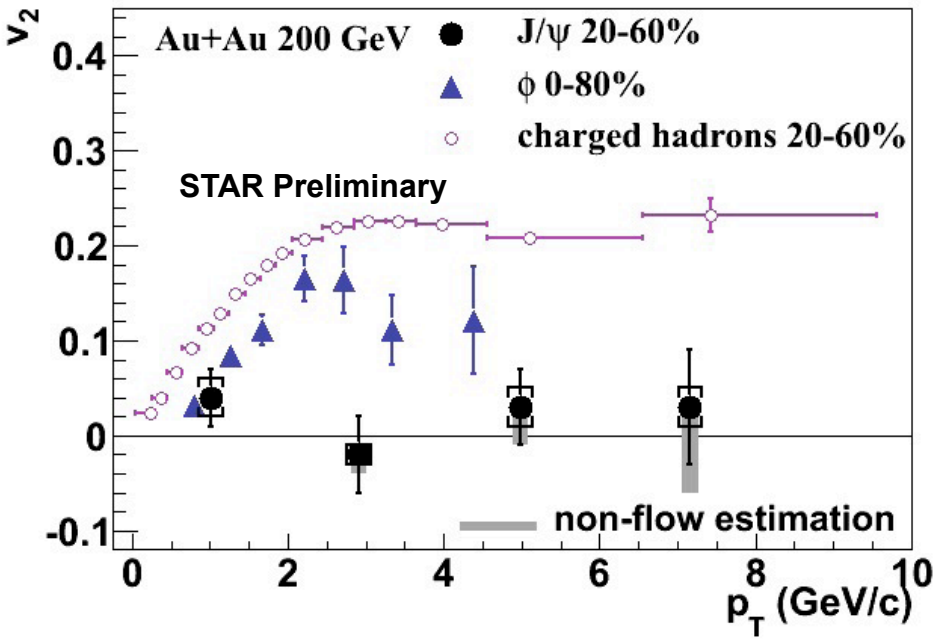
Low p_T D^0 has little constraint on high p_T electrons, and vice versa

Other detectors (ALICE, PHENIX) optimized for higher p_T

though ALICE is looking at an upgrade using HFT technology (~2017?)

More to charm than just *D*'s

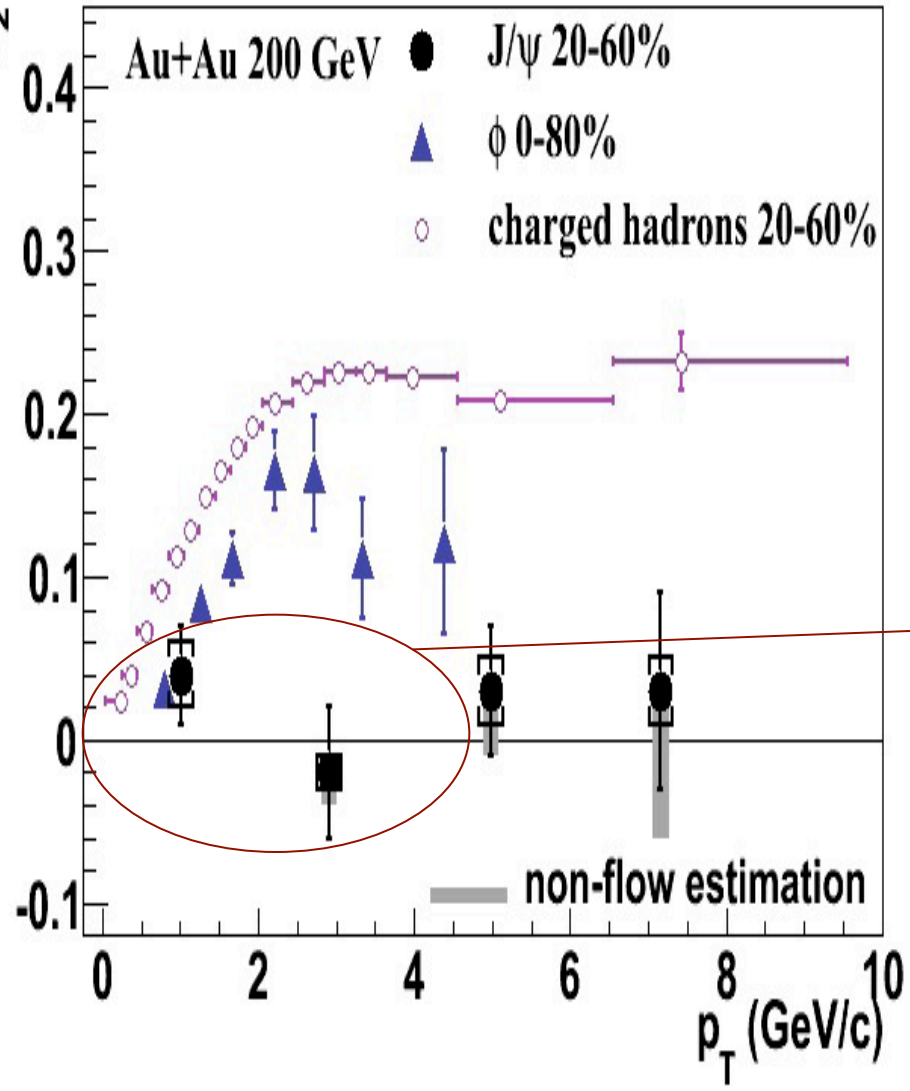




- Are charmed hadrons produced via **coalescence**?
  - Heavy Flavor Tracker: unique access to charm baryons
  - Would force a quantitative **reinterpretation** of non-photonic electron R_{AA}
- Muon Telescope Detector: precision measurements of *J*/ψ flow

J/Psi Flow: MTD projection

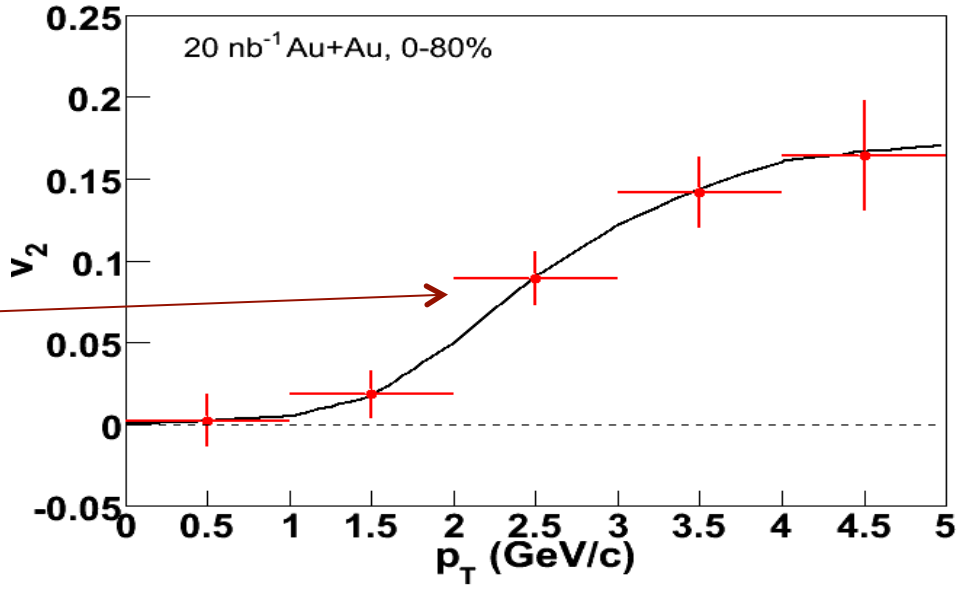
J/Psi v_2 small



Either charm does not flow, or coalescence is not a dominant contributor to J/Psi production

Or charm flows strongly for p_T where coalescence small, and vice versa

[X. Zhao and R. Rapp, Phys. Rev. C 82:064905 (2010)]

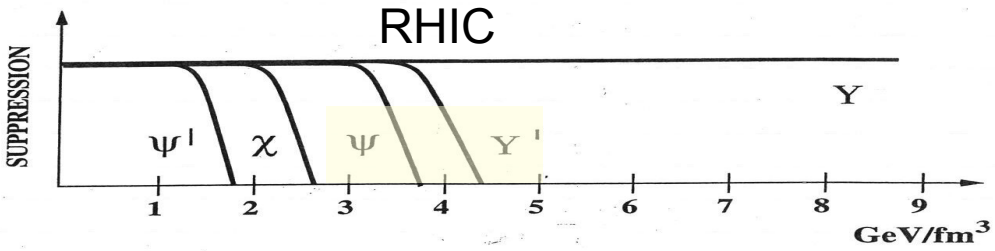


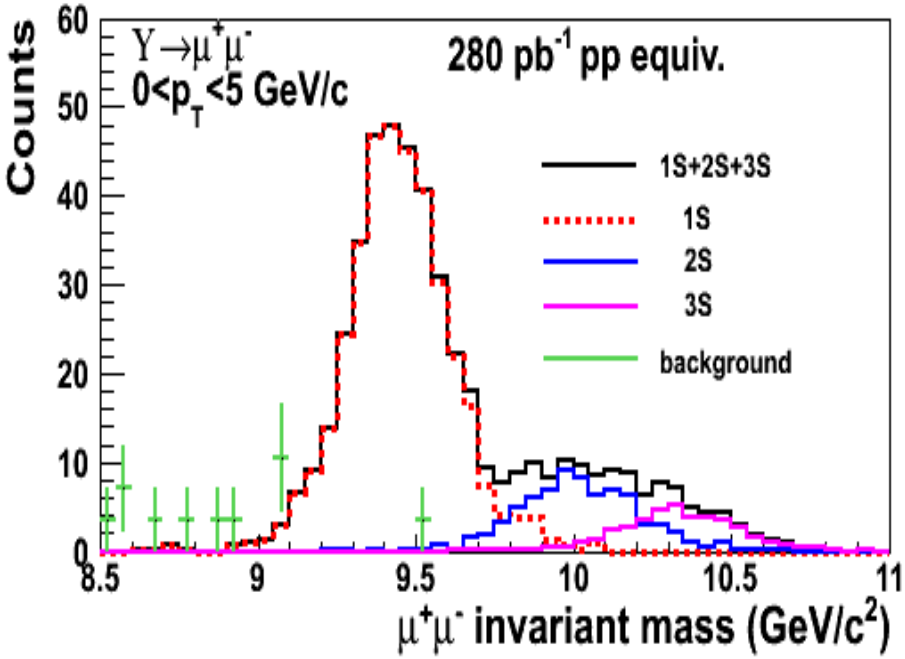
More subtle measurements needed
Dramatic improvement with RHIC II and MTD

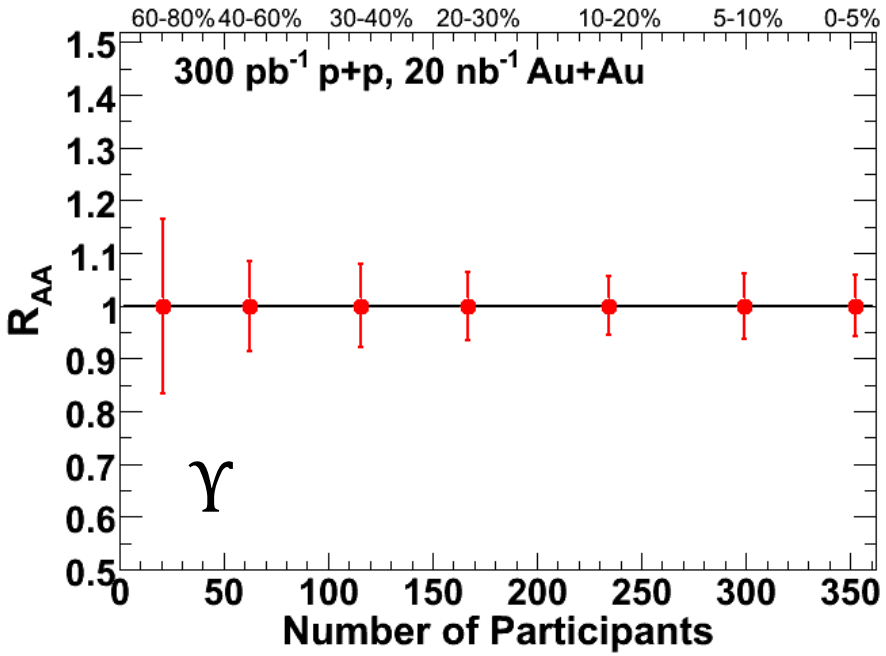
Properties of sQGP: Upsilon

What quarkonia states dissociate at RHIC energy densities?

What is the energy density?

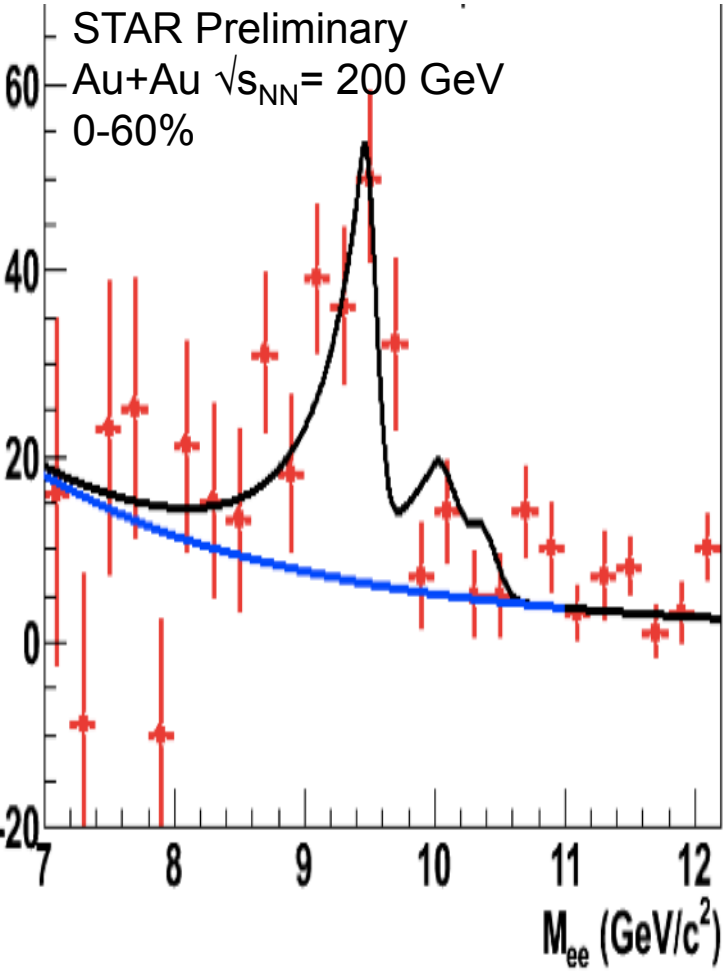


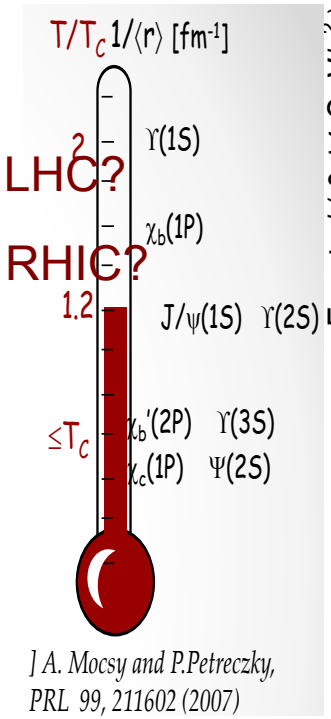


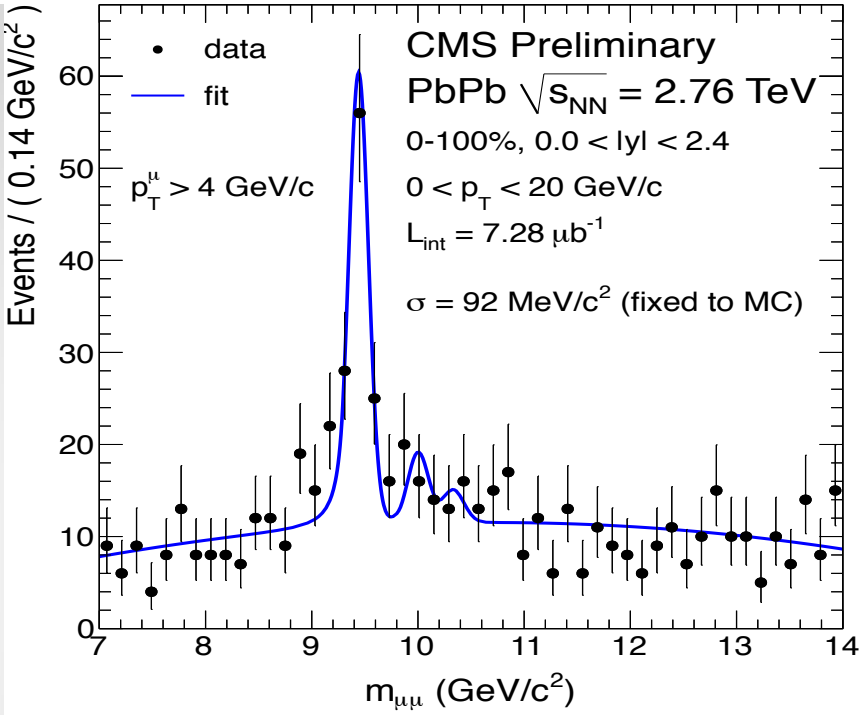


- Muon Telescope Detector: dissociation of Υ, separated by state
  - At RHIC: small contribution from coalescence, so interpretation clean
  - No contribution of Bremsstrahlung tails, unlike electron channel

Upsilon: Complementary to LHC







Similar counts per year between LHC and RHIC:

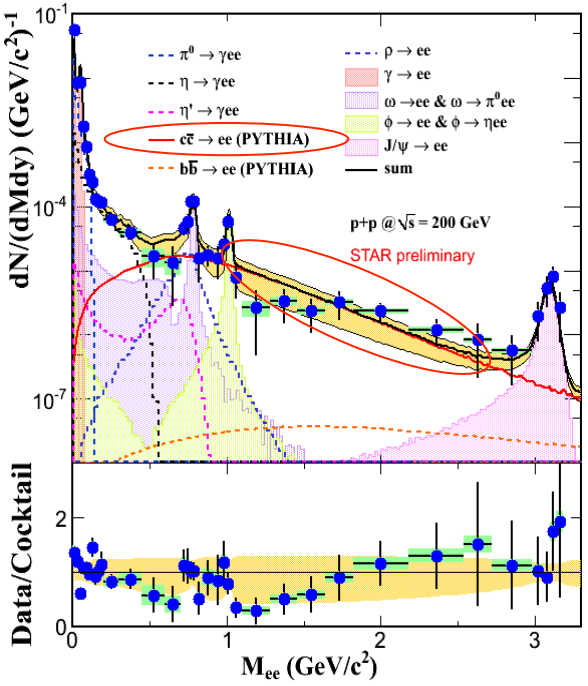
σ (LHC>RHIC) * $\mathcal{L}$ (LHC<RHIC)

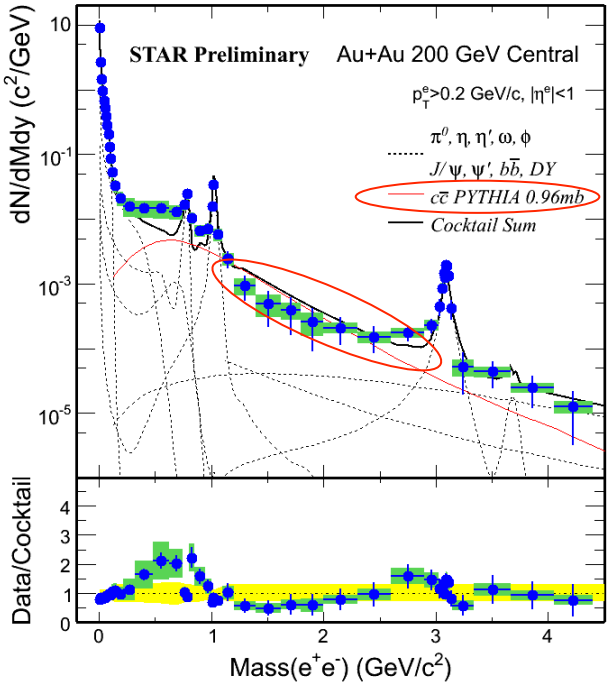
Complementarity:

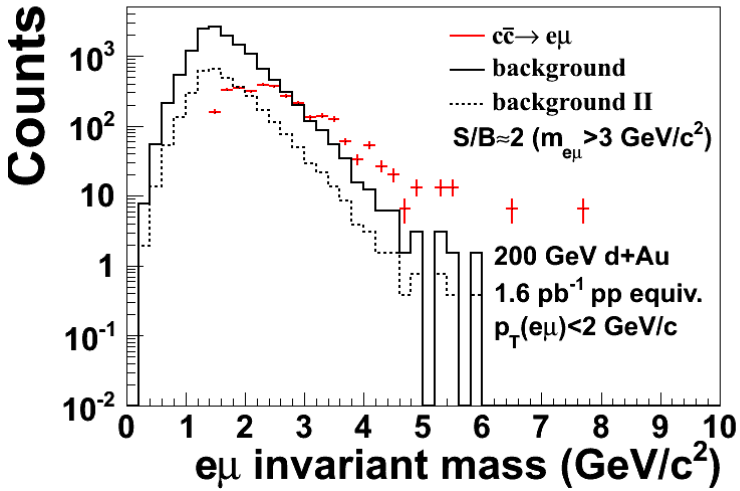
$T_{LHC} \neq T_{RHIC}$

Possible coalescence contribution at the LHC

Properties of sQGP: dileptons







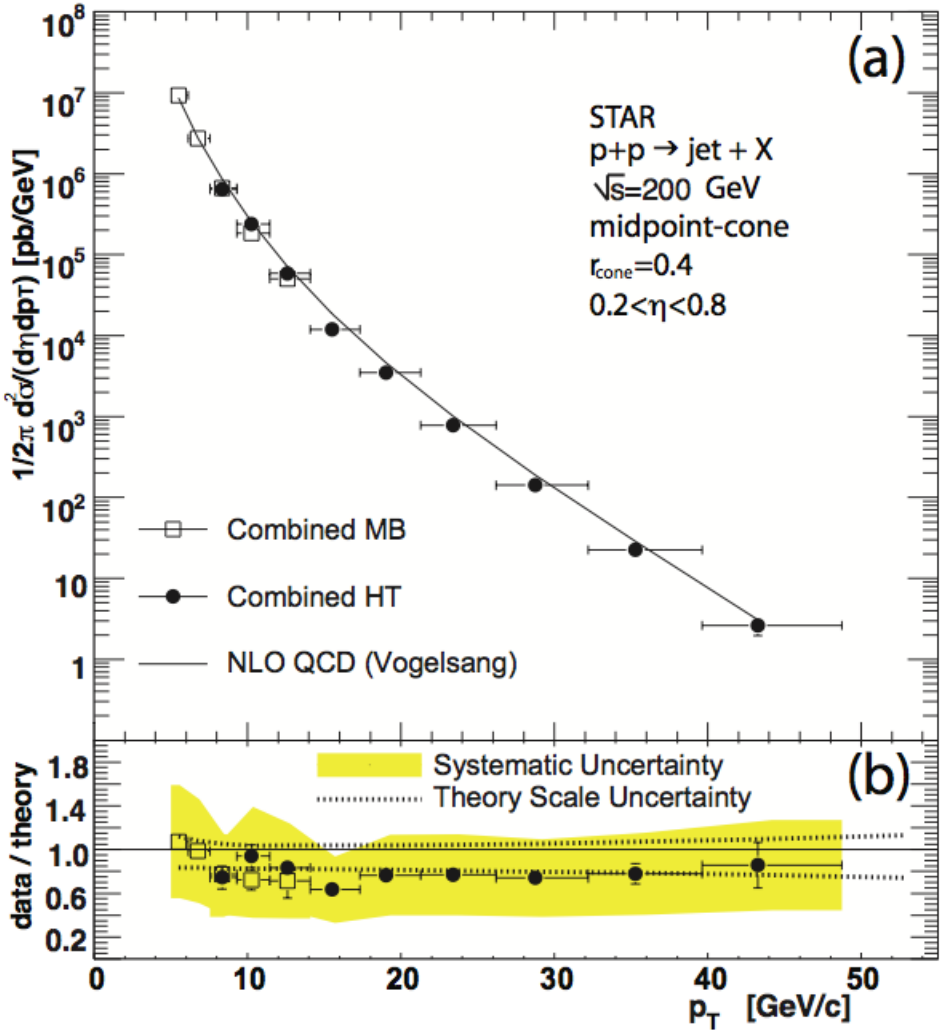
- Penetrating probe of the bulk medium
- Correlated charm dominates 1-3 GeV mass region
  - Large uncertainties in pp
  - Different in A+A?
- Address with:
  - HFT: D^0, displacement
  - MTD: e-μ correlations

Mechanism of partonic energy loss

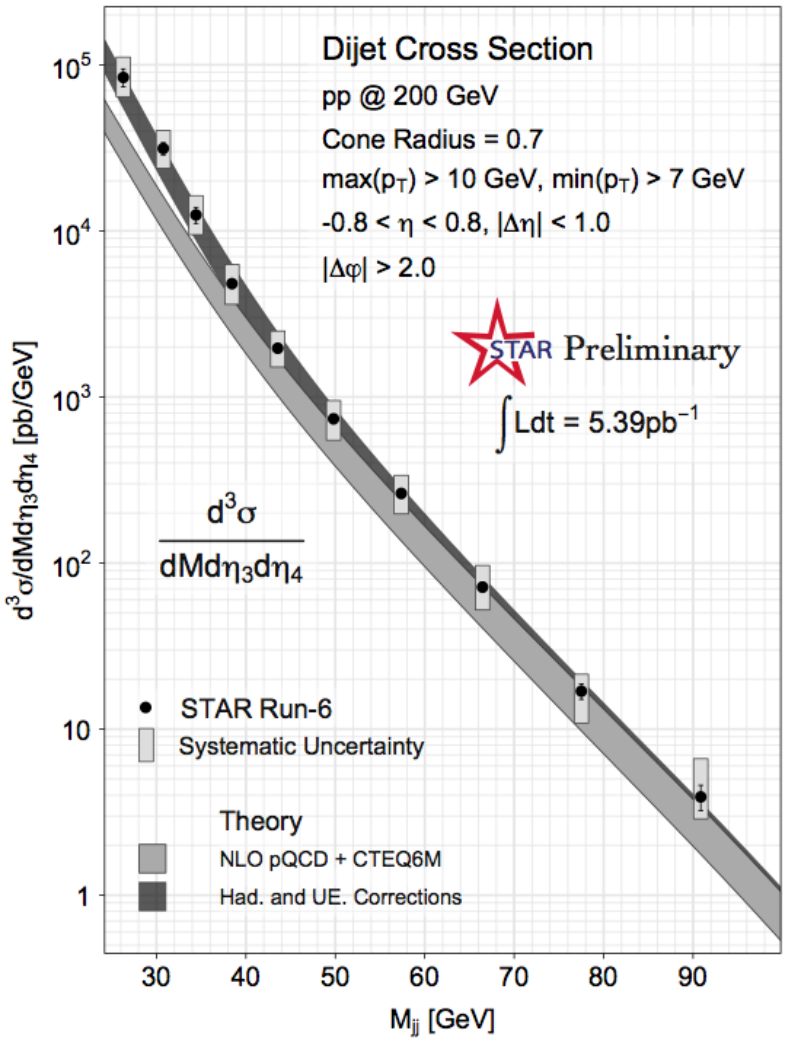
- Is the mechanism predominantly collisional or radiational?
  - Detailed, fully kinematically constrained measurements via gamma-hadron and full jet reconstruction
  - Pathlength dependence, especially with U+U and other systems (Cu+Au)
- Does the mechanism depend on the parton type?
  - Gluons: particle identification, especially baryons
  - Light quarks: gamma-hadron
  - Heavy quarks: Heavy Flavor Tracker and Muon Telescope Detector
- Does the energy loss depend on the parton energy and/or velocity?
  - High precision jet measurements up to 50 GeV
  - Vary velocity by comparing light quarks, charm, and beauty

Jets: Proven Capabilities in p+p

B.I. Abelev et al. (STAR Coll.), Phys.Rev.Lett. 97, 252001, 2006



SPIN-2010: Matt Walker/Tai Sakuma, *for the collaboration*

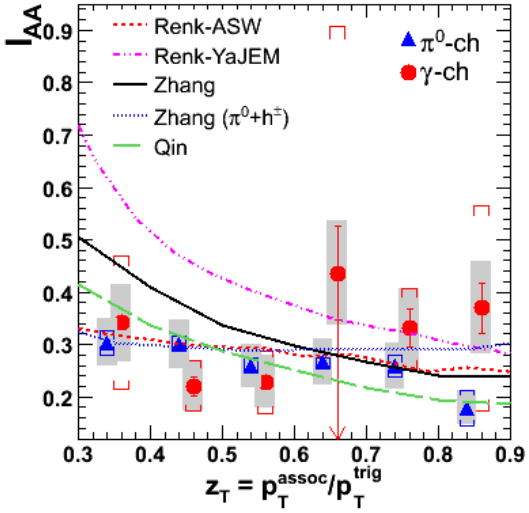


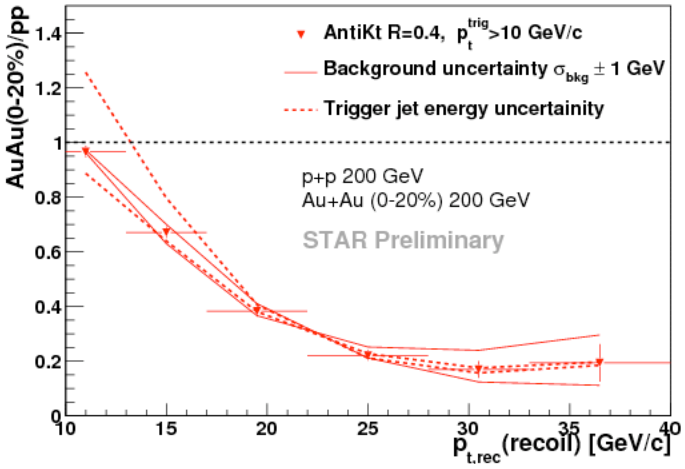
Jets well understood in STAR, experimentally and theoretically

To date: Jets and γ-hadron in A+A

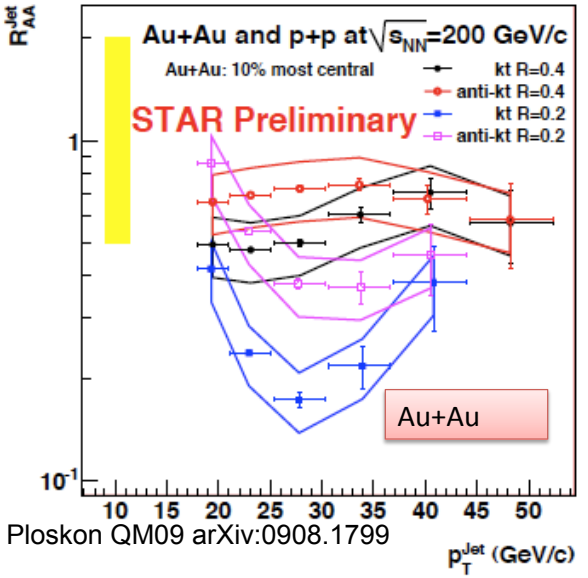
Phys. Rev. C 82, 034909

Triggered: ~0.3 nb^{-1}

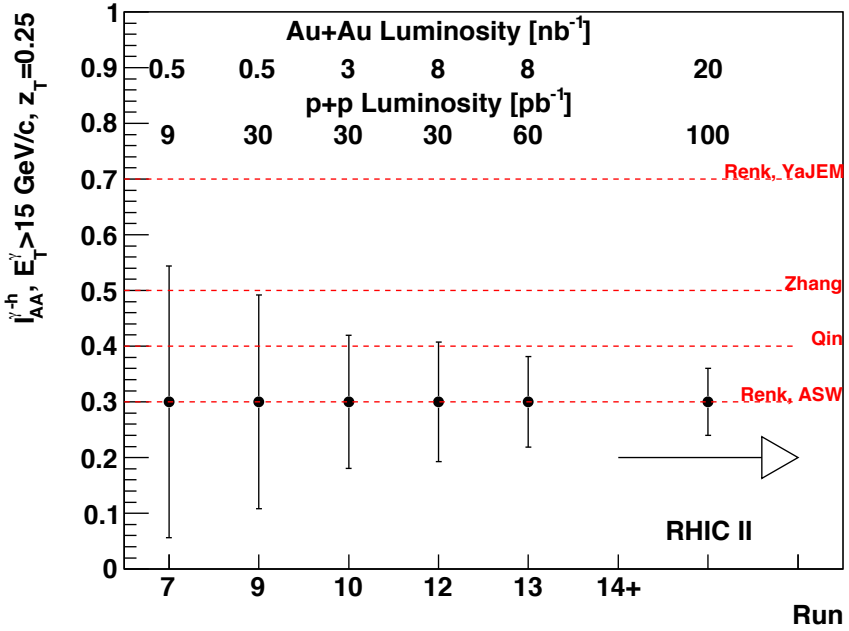




Untriggered: ~0.01 nb^{-1}



M. Ploskon QM09 arXiv:0908.1799



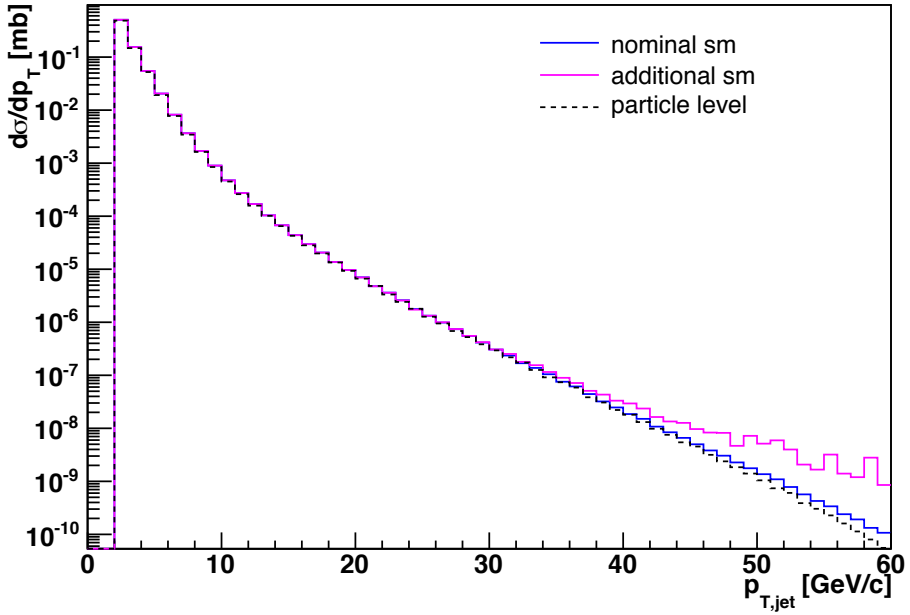
Beginning results indicative, but not final word

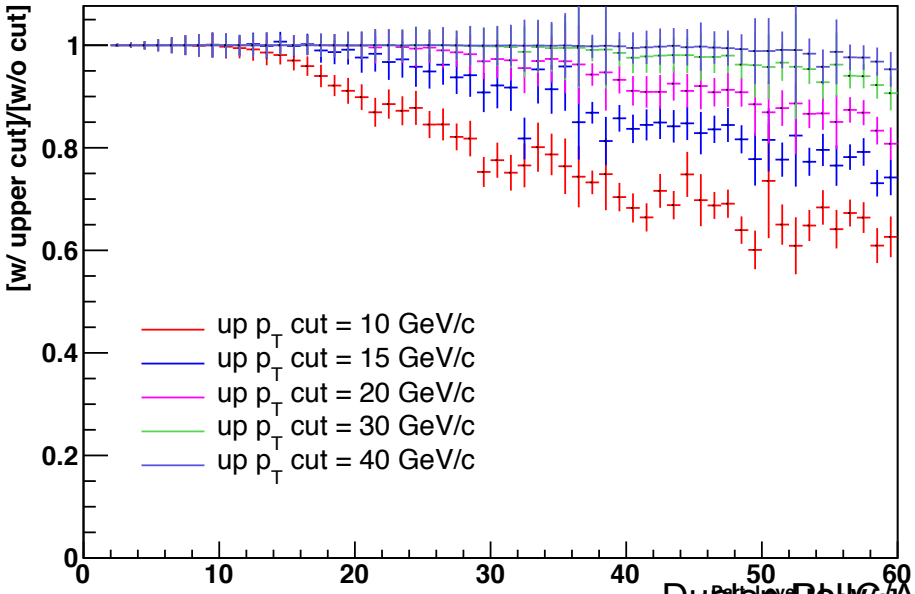
Huge increase in significance with trigger upgrades+luminosity

Complementary to LHC:

RHIC: quarks LHC: gluons

Jet Capabilities in A+A

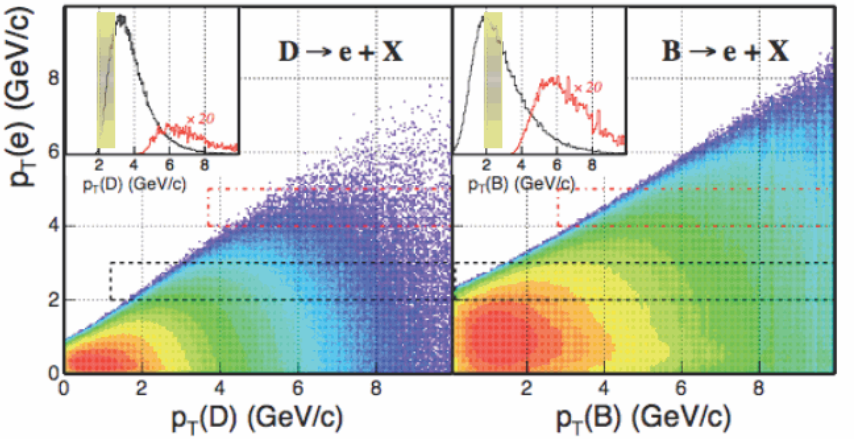


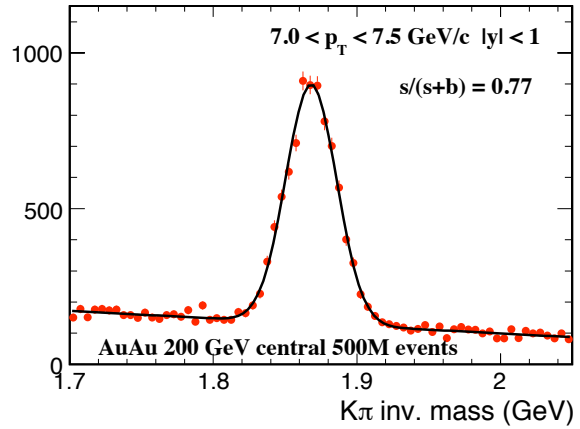


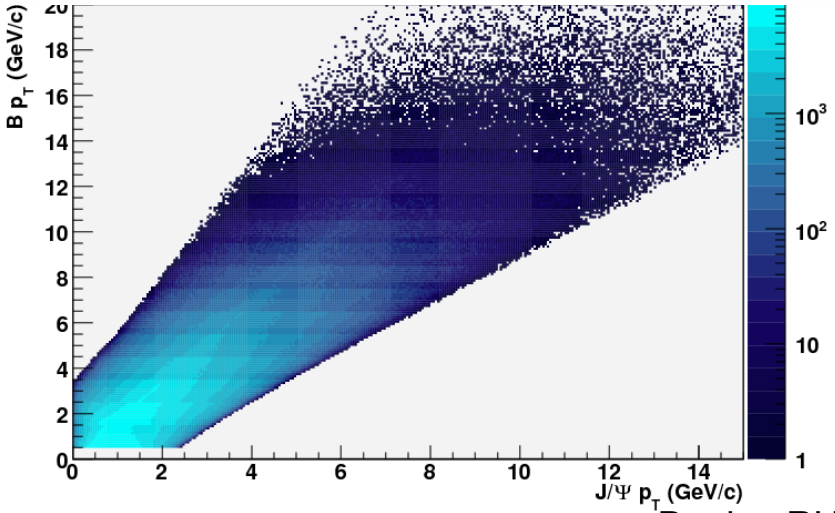
- Sufficient statistical reach out to ~50 GeV for precision measurements
  - Large unbiased datasets
  - Trigger upgrades to lessen bias with walking jet patches
- Smearing of high momentum charged hadrons under control
  - Corrections: need to calibrate level of smearing
  - Hard cutoff in hadrons: small loss of jets that fragment hard
- Dominant uncertainty: fluctuations in the underlying event

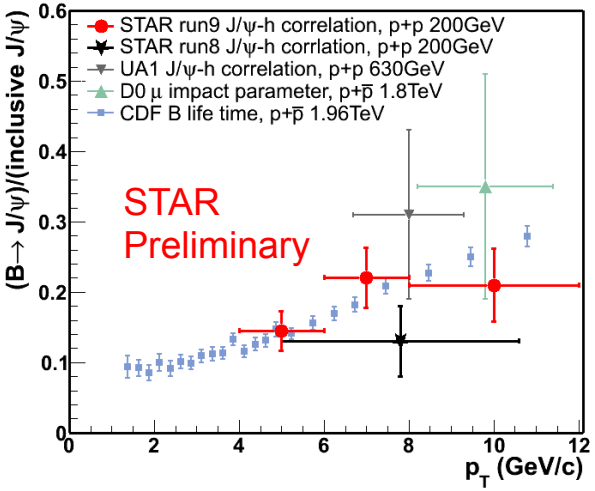
Velocity dependence via Heavy Quarks

- What is the velocity dependence of energy loss?
  - Key tools: heavy quarks with precise kinematic reconstruction
  - Key technology: Heavy Flavor Tracker and Muon Telescope Detector



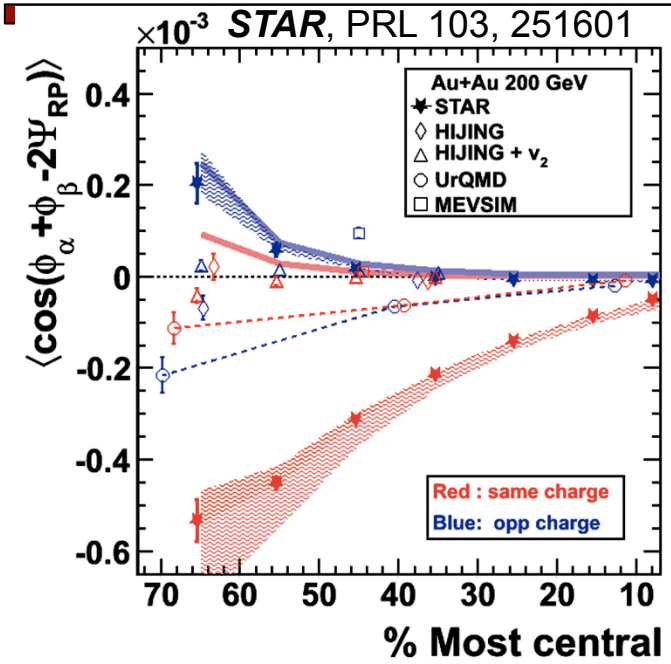


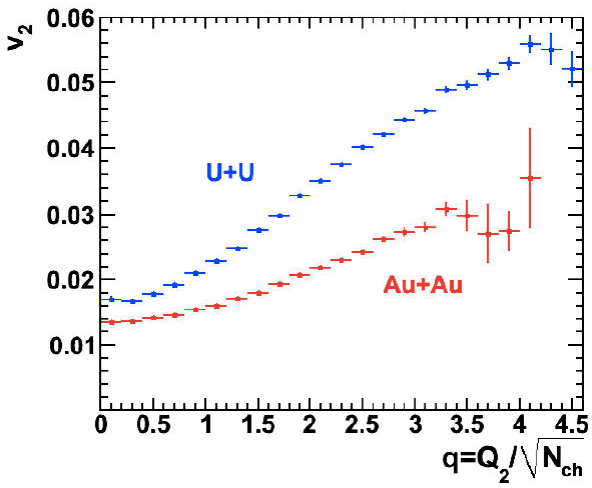


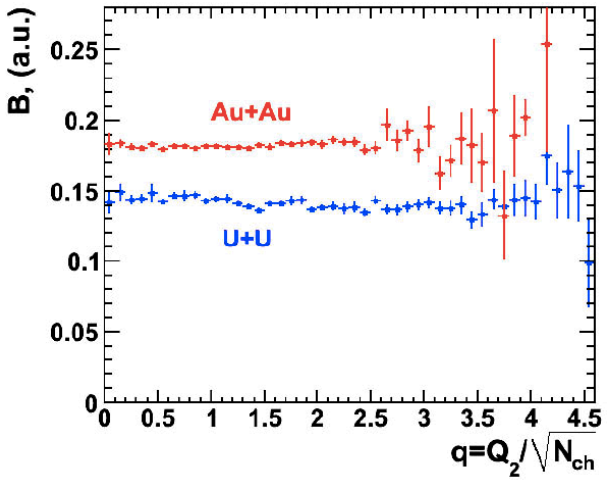


Flexibility of RHIC: System Scans

STAR ☆ Novel symmetries: local strong parity violation

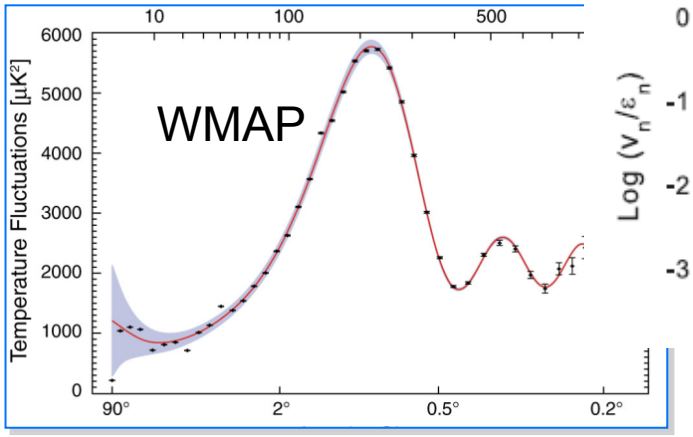


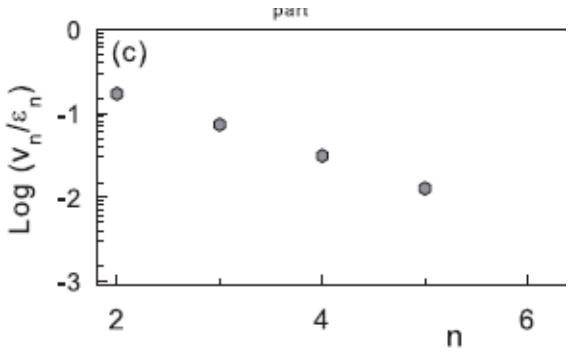


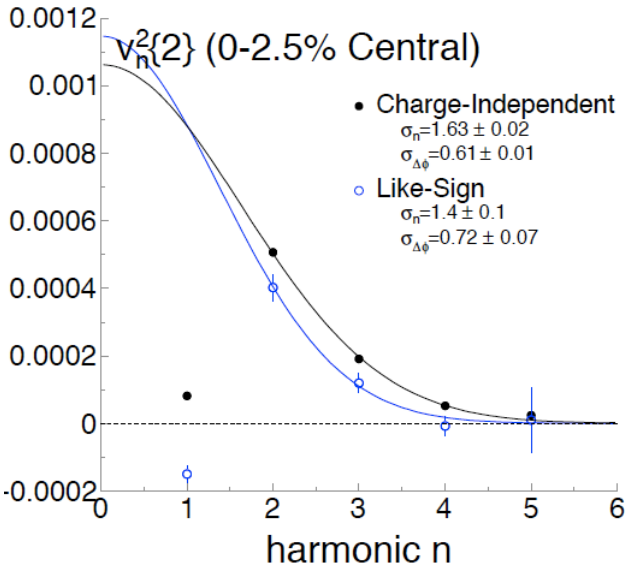


- Transitions between domains with different topological charge may induce parity violation in the dense matter
  - Similar transitions (at much higher energies) might have produced the matter-antimatter asymmetry in the early universe
- Magnetic field in A+A plays a key role: **chiral magnetic effect**
- **Crucial** to verify if parity violation is the **correct explanation**
  - **U+U collisions:** collisions with **more v_2** and **less B field** than Au+Au
  - **Energy scan:** Behavior from 7.7 GeV-2.8 TeV as B field and v_2 change

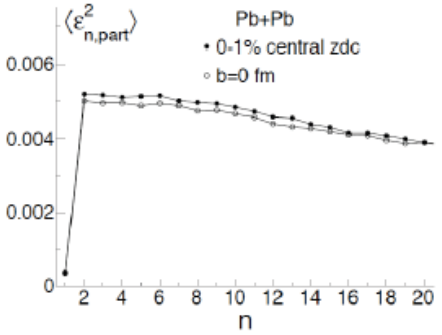
v_n fluctuations: varying initial conditions



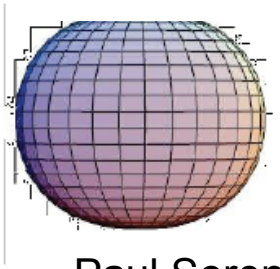


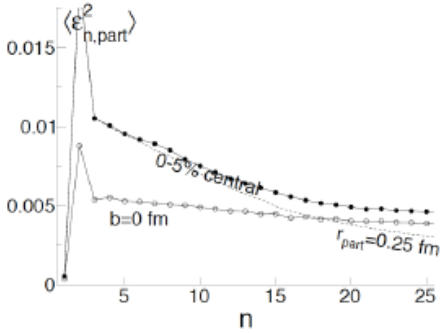


Pb 208



Au 197





Damping of higher harmonics: viscosity

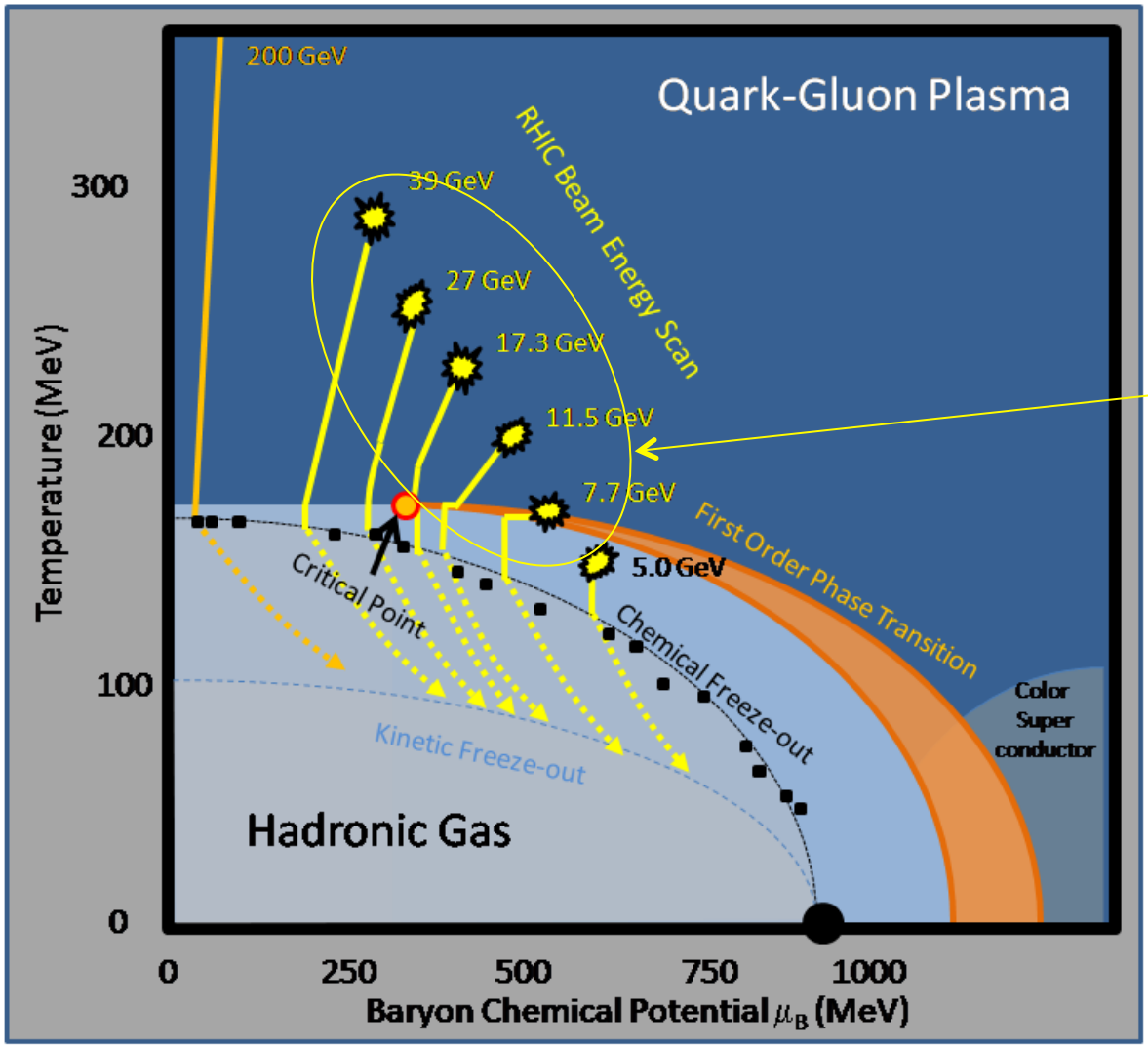
Check interpretation by varying initial conditions: damping unchanged?

Run 12: U+U
Run 13 and beyond: Pb+Pb, Cu+Au, …

Paul Sorensen

Phases of QCD

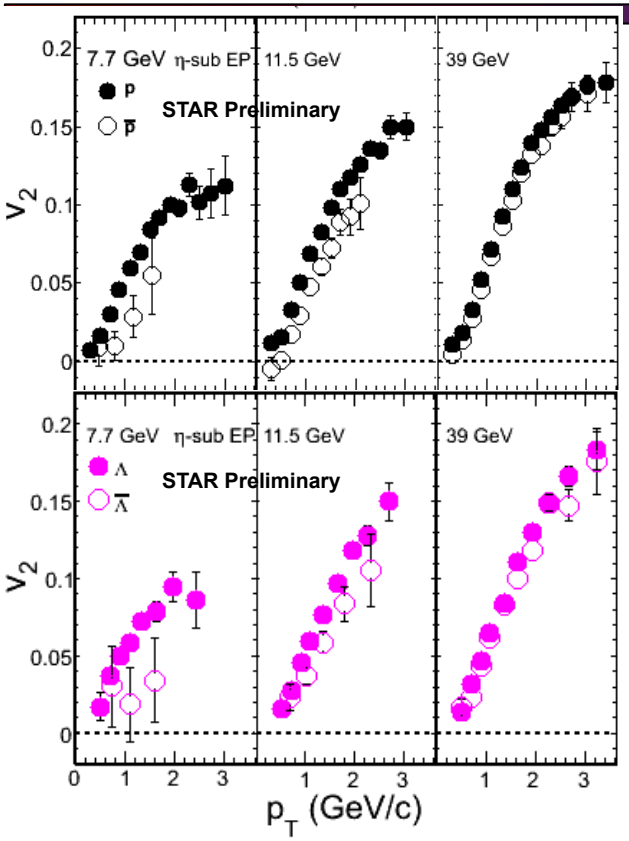
Where is the QCD critical point?

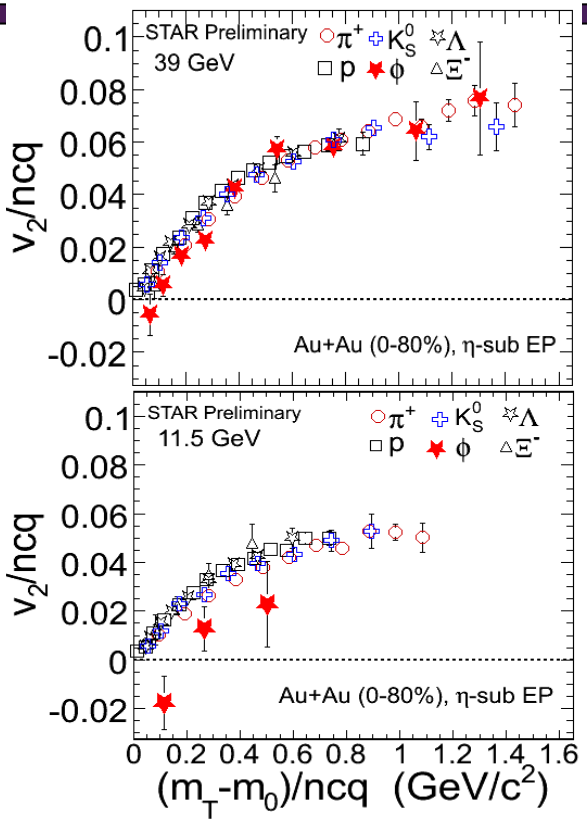


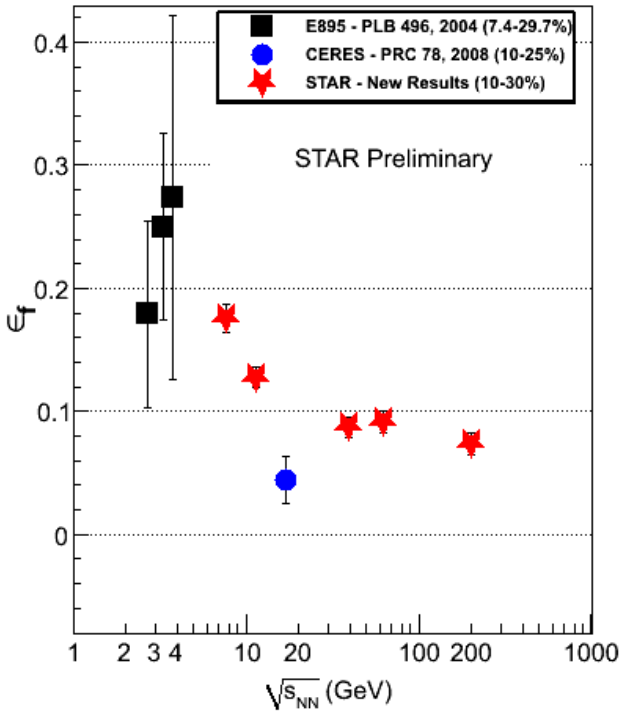
Phase 1
Finished in
Runs 10-11

A **landmark on the QCD phase diagram**

Narrowing down the region of interest



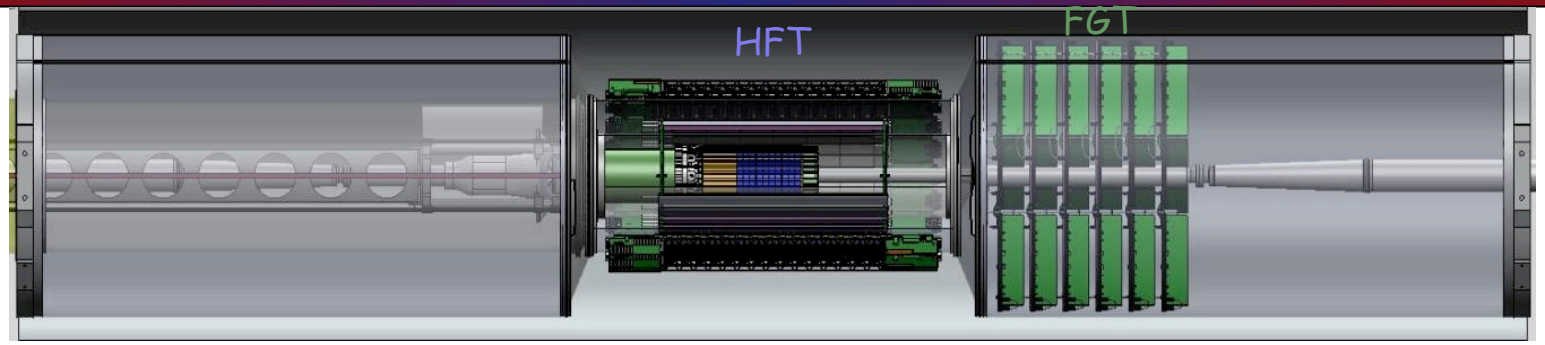


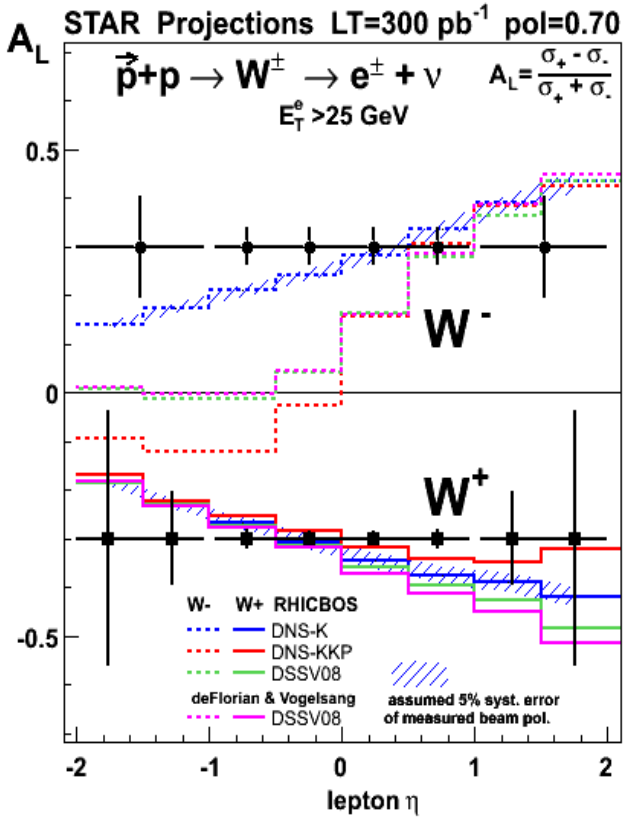


- 39, 62, and 200 GeV collisions are qualitatively similar
- Even extends to LHC energies
- But **many changes** appear **at lower energies**
- Narrowing down the region of interest with Phase 1
- Future: **need detailed study of the key region**
  - Finer energy steps with higher statistics

Spin

Forward GEM Tracker



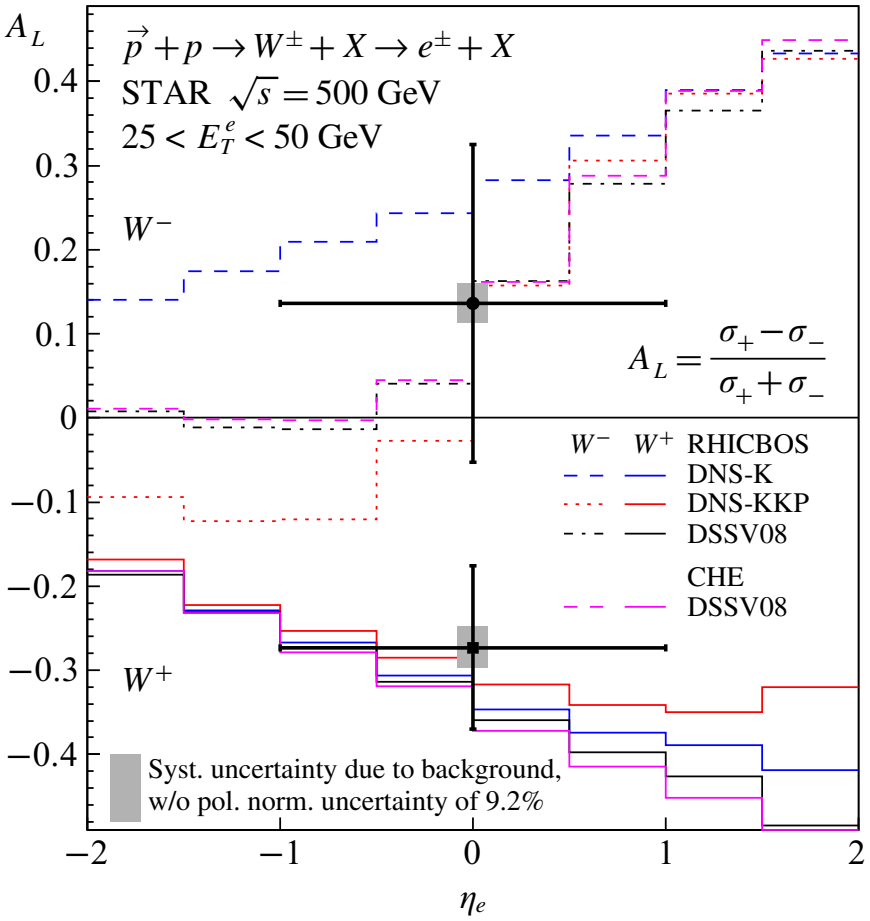


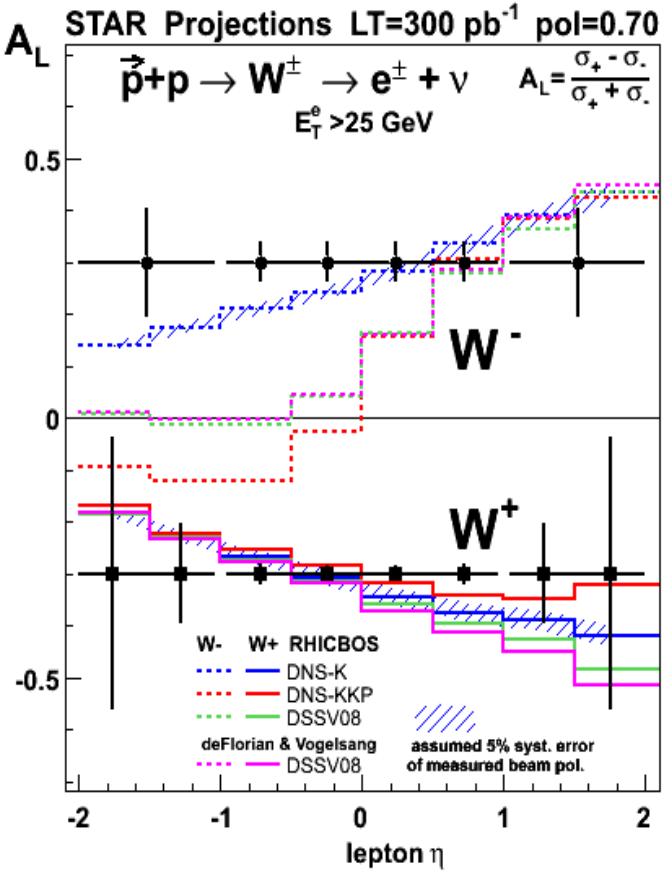
1) FGT: RHIC Capital Equipment project
2) Six light-weight triple-GEM disks
3) New mechanical support structure
4) Planned installation: Summer 2011

1) Full charge-sign discrimination at high-p_T
2) Design polarization performance of **70% or better** to collect at least 300pb^{-1}
3) **Ready* for Run 12!**

*** minimal configuration**

Quark Flavor Measurements: $W^{\pm}$

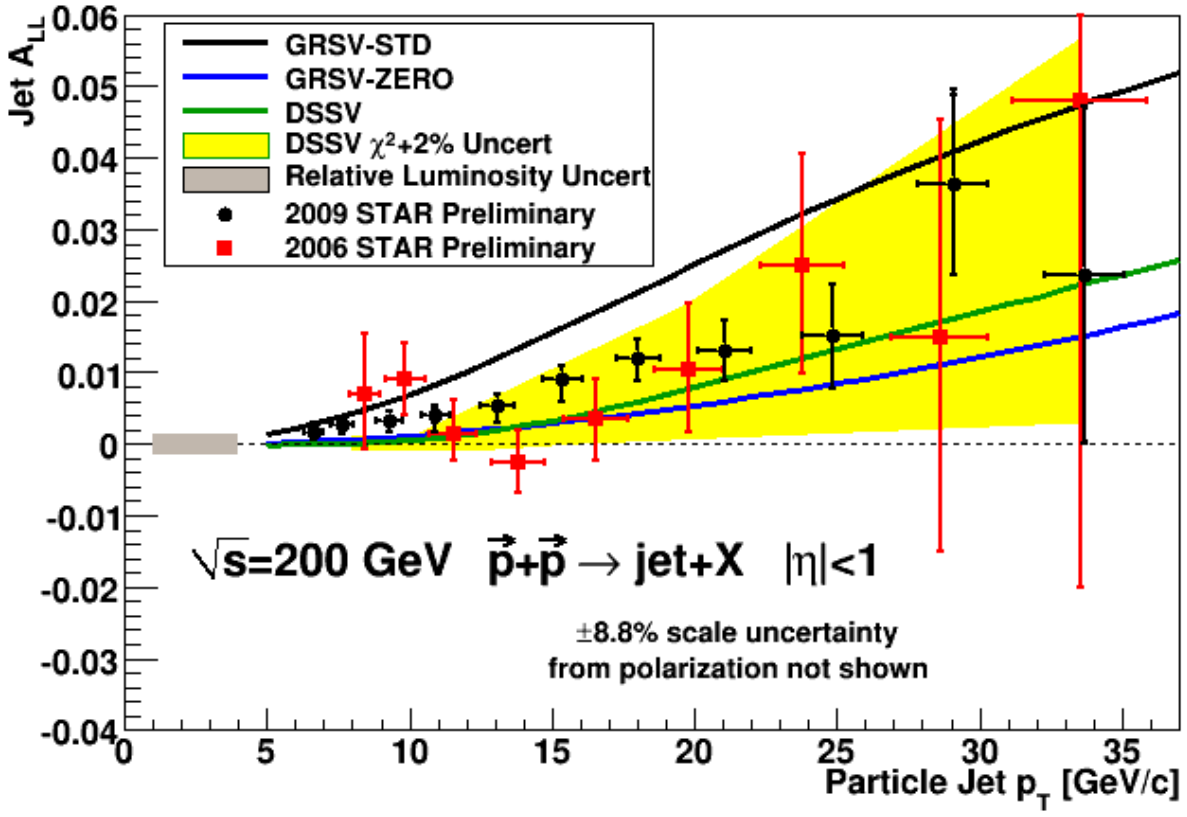




1) STAR first results* consistent with models: Universality of the helicity distribution functions
2) Precision measurements require **large luminosity** and **high polarization** at RHIC

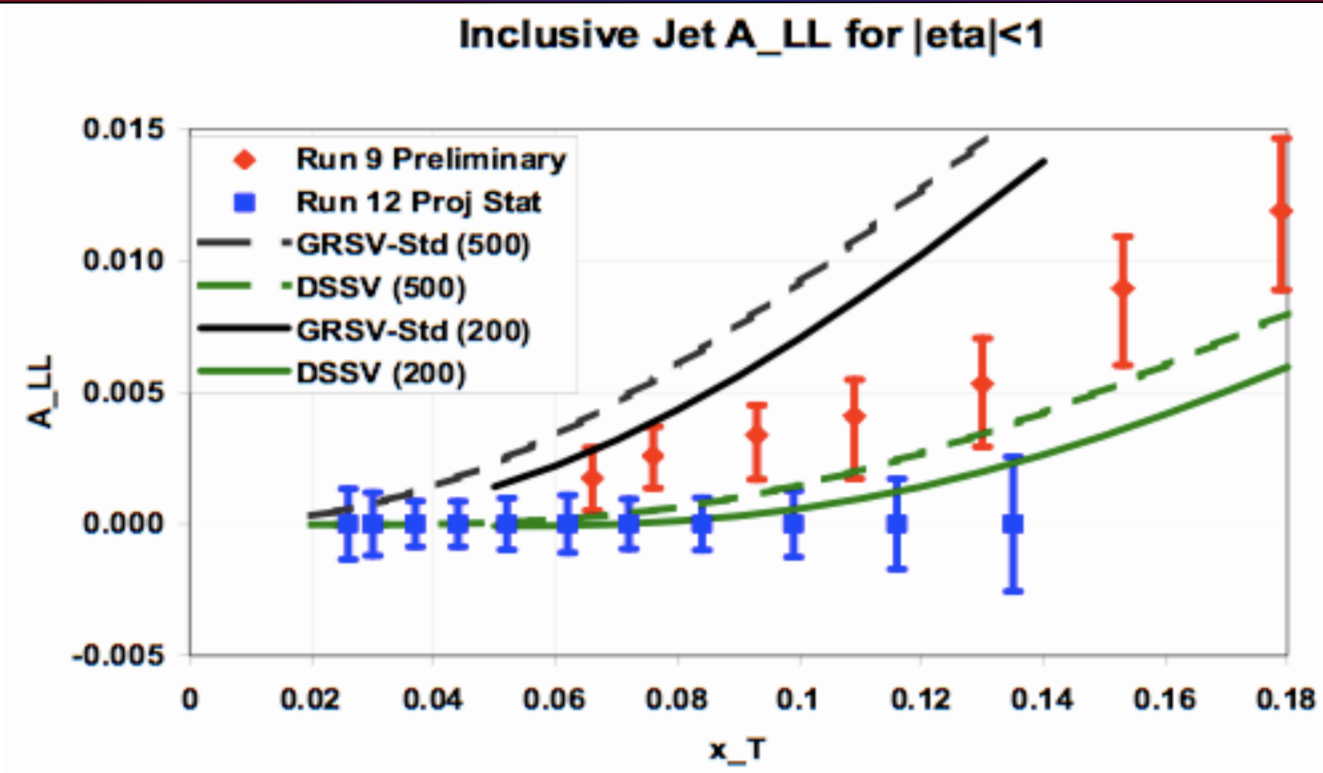
* STAR: PRL 106, 62002(2010).

STAR A_{LL} from 2006 to 2009



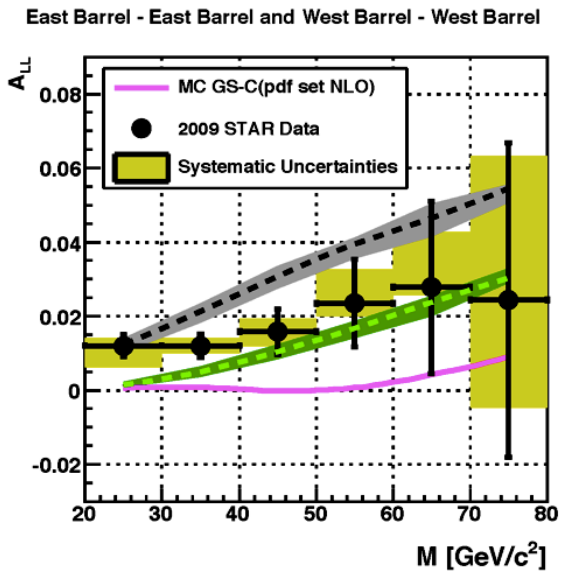
- 2009 **STAR** A_{LL} measurements:
- **Results fall between predictions from DSSV and GRSV-STD**
- Precision sufficient to merit finer binning in pseudorapidity

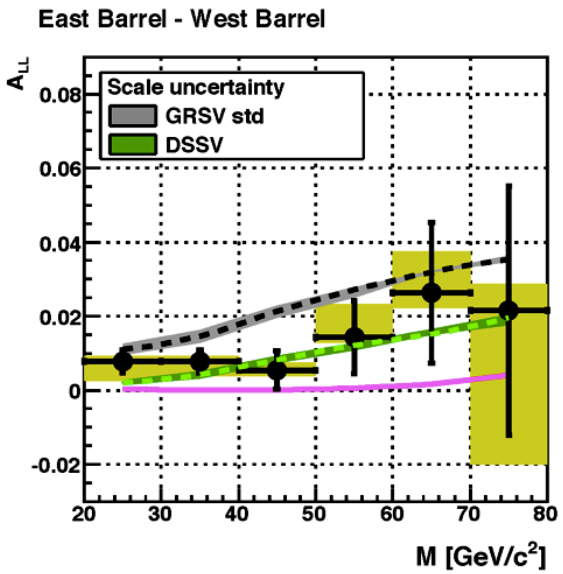
Expected inclusive jet A_{LL} precision

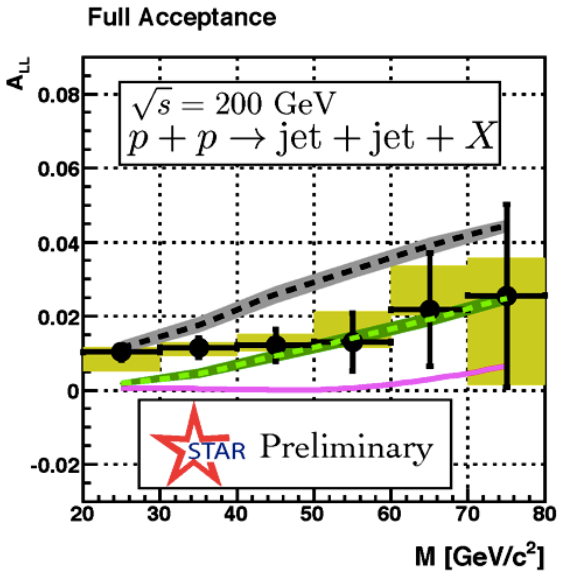


- Run 12 (500 GeV) useful complement to Run 9 (200 GeV)
- 200 GeV: Run 13 uncertainties, as compared to Run 9:
  - A factor of ~2 for jet E_T >~ 12 GeV
  - A factor of ~sqrt(2) for jet E_T <~ 12 GeV

Di-jet A_{LL}(2009)



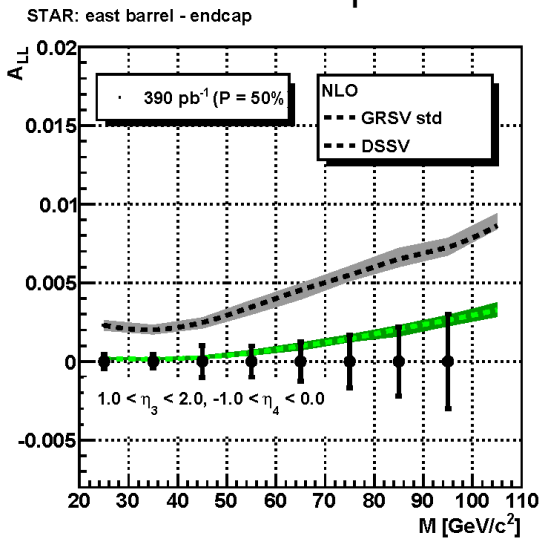


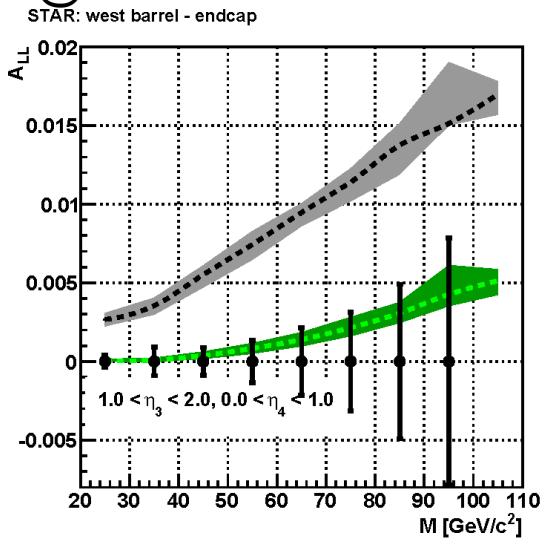


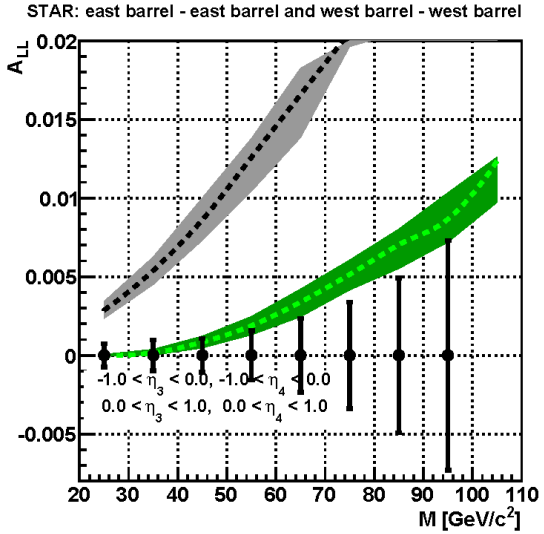
- For fixed M, different kinematic regions sample different *x* ranges
  - East-east and west-west sample higher x_1, lower x_2, and smaller |cos(θ*)|
  - East-west samples lower x_1, higher x_2, and larger |cos(θ*)|
- A_{LL} falls between DSSV and GRSV-STD

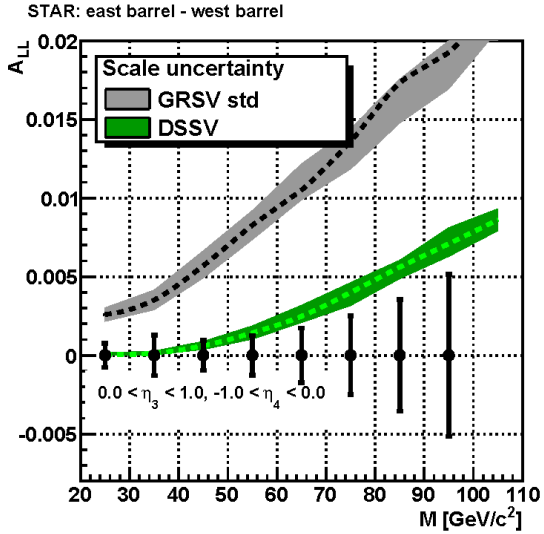
Expected di-jet A_{LL} sensitivity at 500 GeV

Assumes 600 pb^{-1} delivered @ P = 50%







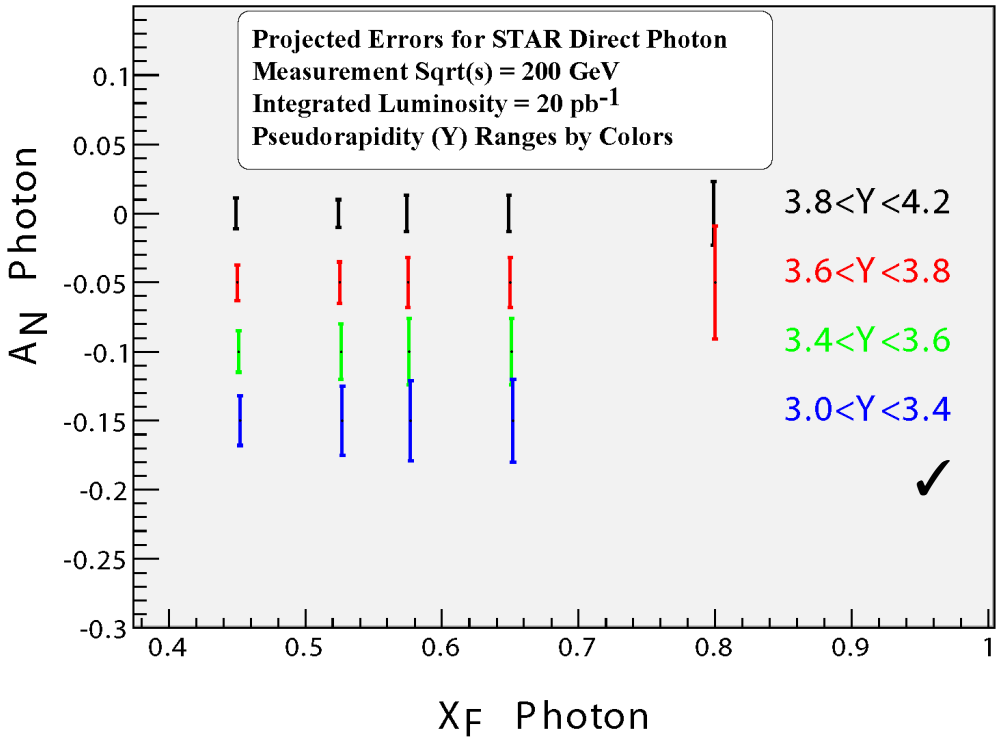


$$x_1, x_2 = \frac{M}{\sqrt{s}} \exp\left(\pm \frac{\eta_3 + \eta_4}{2} \right)$$

- Higher energy accesses lower x_g
- Expect smaller A_{LL}
- Projections include information on trigger rates, etc.
- Uncertainties shown are purely statistical
- May add EEMC-EEMC di-jets to reach lowest x values once FGT is installed

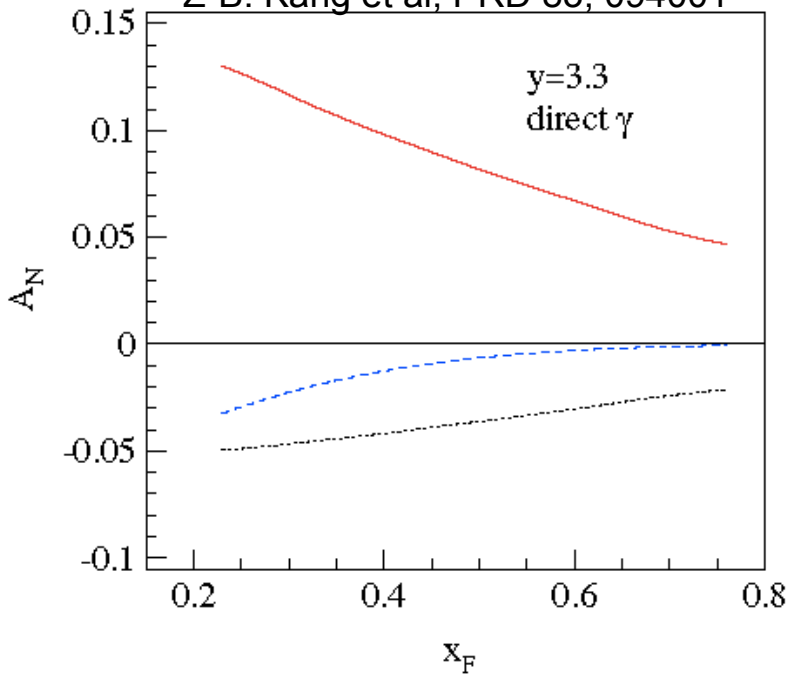
Transverse: A_N for direct photons

Expected **STAR** precision



Recent model predictions

Z-B. Kang et al, PRD 83, 094001



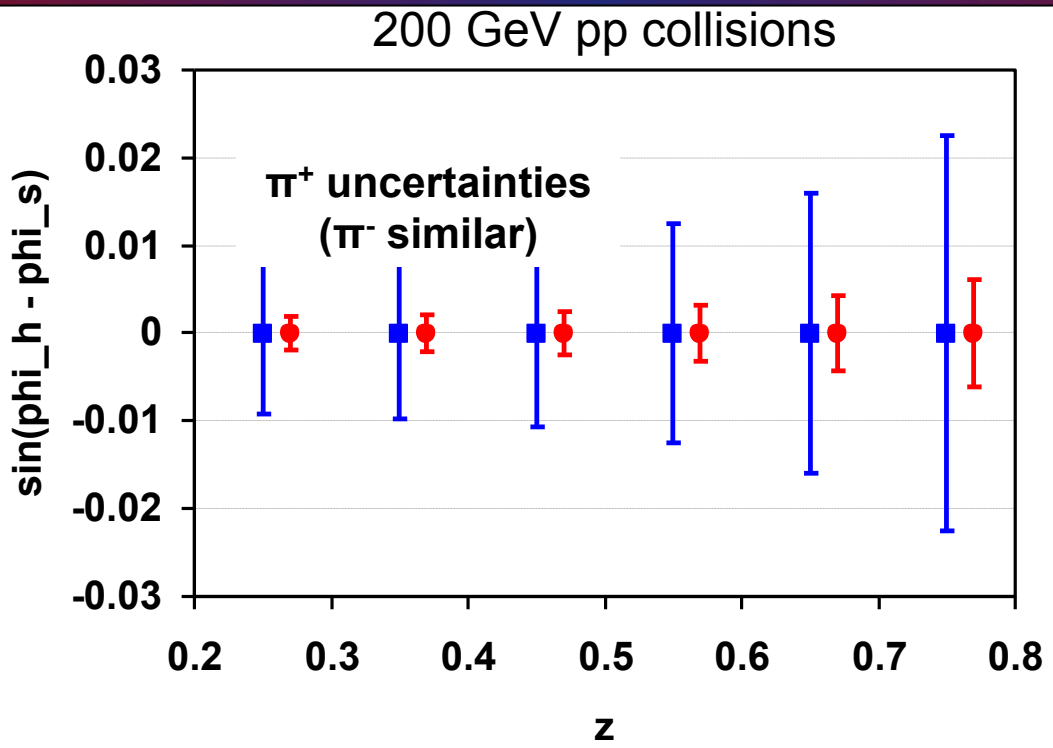
Very significant measurement of direct photon A_N at forward y

Wide range of additional measurements at both 200 and 500 GeV:

Forward-y: π^0, η A_N with extended p_T reach; neutral jet-like clusters

Mid-y: W A_N; Interference FF and Collins from jets; Sivers dijets

Mid-rapidity Collins asymmetry in jets



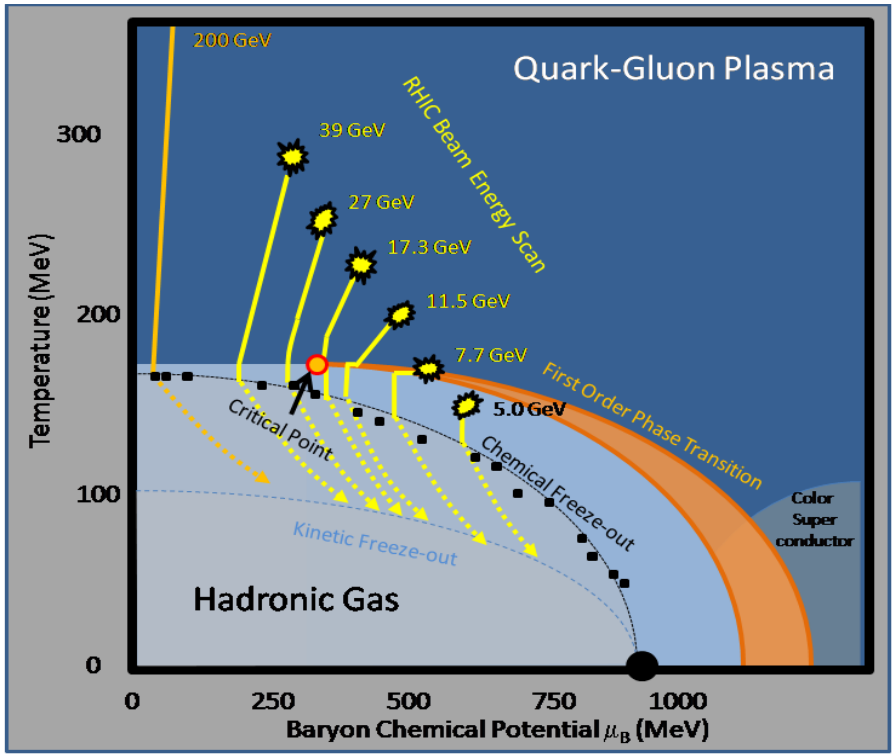
Current uncerts (stat+syst) in Run 6 analysis

Projected uncerts (stat+syst) for 20 pb^{-1} with 60% pol

- Reconstruct full jet in $0 < \eta < 1$
- Measure azimuthal asymmetry of charged pions about jet thrust axis
- **Expect asymmetries of a few percent**; opposite signs for π^+ vs π^-

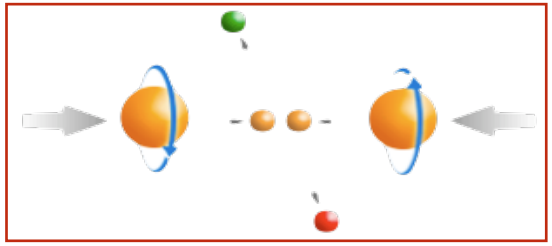
Summary: significant progress in next 5 years ✓

Hot QCD Matter

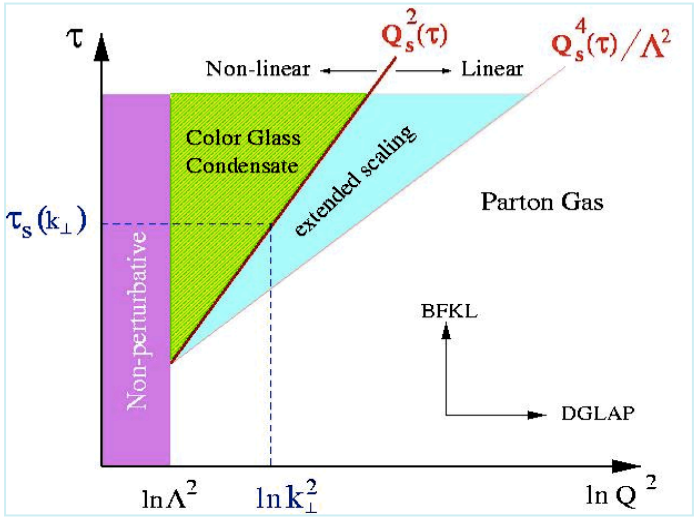


Properties of the sQGP in detail ✓
Mechanism of Energy Loss:
weak or strong coupling? ✓
Is there a critical point, and if so, where? ✓
Novel symmetry properties ✓
Exotic particles ✓

Partonic structure



✓ Spin structure of the nucleon
✓ How to go beyond leading twist and colinear factorization?



❍ What are the properties of cold nuclear matter?

Backup

STAR Experiment as of 2014